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Paper Title: Hypothesis Testing of Edge Organizations: Empirically Calibrating an Organizational Model for Experimentation

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14. ABSTRACT
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Hypothesis Testing of Edge Organizations: Empirically Calibrating Organizational Models for Experimentation

Abstract

This paper presents our ongoing efforts to model, simulate, and eventually optimize work and knowledge flows in Edge organizations. We use the extended POW-ER 3.2 framework to model and compare two organizational forms (Edge vs. Hierarchy) to structure participants in a counter-intelligence student exercise, ELICIT — first without, and then with, learning micro-behaviors enabled in POW-ER 3.2. Empirical, experimental data on learning and forgetting from observations of student teams conducting repeated trials of the AROUSAL (Lansley, 1982) business simulation exercise at Stanford are used as the basis for calibrating agent learning and forgetting micro-behaviors derived from the cognitive psychology literature. We then compare empirical observations of student teams conducting the ELICIT exercise for both *Edge* and *Hierarchy* structural configurations with outputs from POW-ER 3.2 computational simulation models representing teams executing the ELICIT exercise in these two structural configurations. This initial comparison has the potential to further calibrate and validate POW-ER for potential use in analyzing and designing C2 organizations. Future output from ELICIT experiments and other empirical data on learning and forgetting will augment our initial comparison. Calibrated POW-ER 3.2 learning and forgetting micro-behaviors will improve the ability of POW-ER to model and simulate organization-level C2 knowledge flows in Edge vs. Hierarchical organizations.

Introduction and Motivation

Recent rigorous testing and comparing of Edge (Alberts and Hayes, 2003) and Hierarchy C2 organizational structures has improved our understanding of the effects of Edge versus Hierarchy structures in terms of organizational performance (Orr and Nissen, 2006 and Nissen, 2005). Earlier efforts focused on the testing and analysis of the efficacy and suitability of Edge vs. Hierarchy organizational performance under Industrial Age vs. 21^{st} Century conditions (Orr and Nissen, 2006) yet, did not address the topic of individual learning and forgetting and its impact on organizational performance.

This paper continues these efforts to model, simulate and eventually optimize work and knowledge flows in Edge organizations, by comparing empirical, experimental data from an exercise (ELICIT), for both structural forms, with output from an organization simulation model (POW-ER 3.2) for each structural form. This enables us to further calibrate and validate the POW-ER 3.2 model in a C2 context to examine the performance differences between Edge and Hierarchy structures engaged in similar project-oriented tasks. We will leverage the recent extension to POW-ER 3.2 that embeds learning and forgetting micro-behaviors empirically determined from the literature and calibrated in the AROUSAL exercise. This enables us to move beyond qualitative reasoning to measure and report the quantitative impacts of individual learning and forgetting on organizational performance outcomes for the two structures.

We begin by illustrating our concept of both Edge and Hierarchy organizations. In *Power to the Edge*, Alberts and Hayes (2003) portray an *agile* organizational form whose high level of responsiveness to rapidly changing conditions relies on decomposing command and control by moving power deliberately to the "edge"—the front line of these organizations where they confront and interact with their environments. We therefore envision an Edge organization to resemble a fully connected network of agents who, at any time, gain knowledge from any other agent as shown in the figure below.

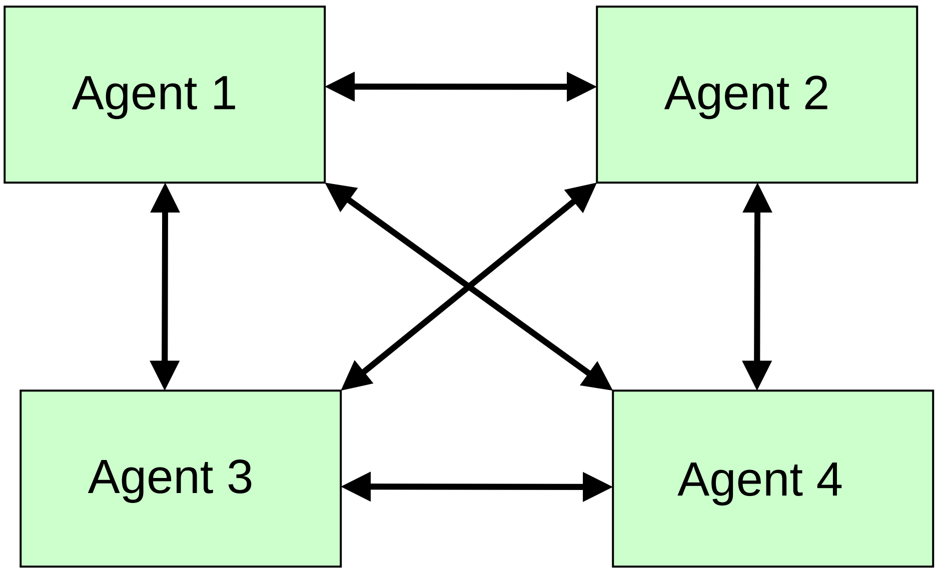

Figure 1: Edge Organization showing communication links, with concomitant knowledge flows, between all agents.

Edge organizations foster *shared awareness* among all the agents as well as open communication of knowledge flow. There is no absolute leader, but leadership emerges, at different times, based on a meritocracy among capable and knowledgeable players.

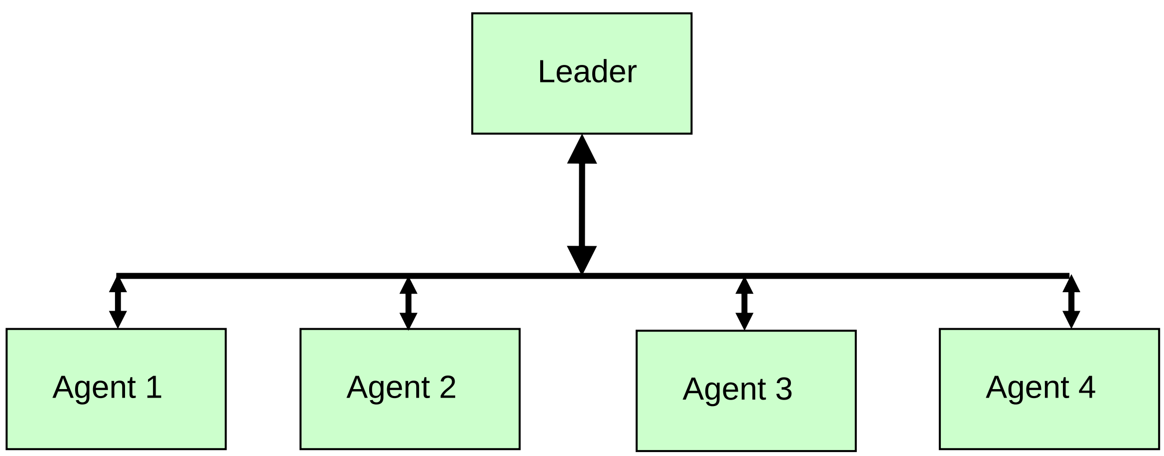

Figure 2: Hierarchy Organization showing communication links and concomitant knowledge flows between agents and their superiors.

A hierarchy organization enforces communication limits between players. Hierarchies are necessary when: highly specialized knowledge, security, or permission is required. This organization can be less *agile* in instances where each agent must act quickly in coordination with the actions of other agents, based on its own state of knowledge, information and instructions, communicated up and down the hierarchy, respectively.

Efficient knowledge management is critical to mission and project success (Cole 1998, Grant 1996, and Spender, 1996), yet few studies have explored the organizational effect of individual skill learning together with individual forgetting as a project continues and its participants improve their skills through repeated performance of tasks or lose their skills through non-performance. To our knowledge, no previous research has explored knowledge flow impacts on Edge organizations. This motivates us to explore and compare organizational effects of individual learning and forgetting in both Edge and Hierarchy structures as skill learning and forgetting occur over time during the ELICIT exercise, and apply our findings to further calibrate these effects in the POW-ER 3.2 agent microbehaviors.

The following section discusses previous efforts to model and compare knowledge flows between Edge and Hierarchy organizations.

Background

Individual Knowledge Flow

Knowledge flows into individuals as they learn, and flows out as they forget; yet the psychological and neurological processes by which people learn and forget are extremely complex. We would be naïve to believe that we might explain all that there is to know about how humans learn and forget in a few short paragraphs. We will narrow our concern to the length of time required for an individual to complete a skill, or processing speed (e.g. Argote, 1999; DeKeyser, 1997; and Laird, Newell, and Rosenbloom, 1987), for the purpose of this study. Conceptually, we do not attempt to quantify knowledge directly, but instead measure skill completion time as a surrogate measure for knowledge held.

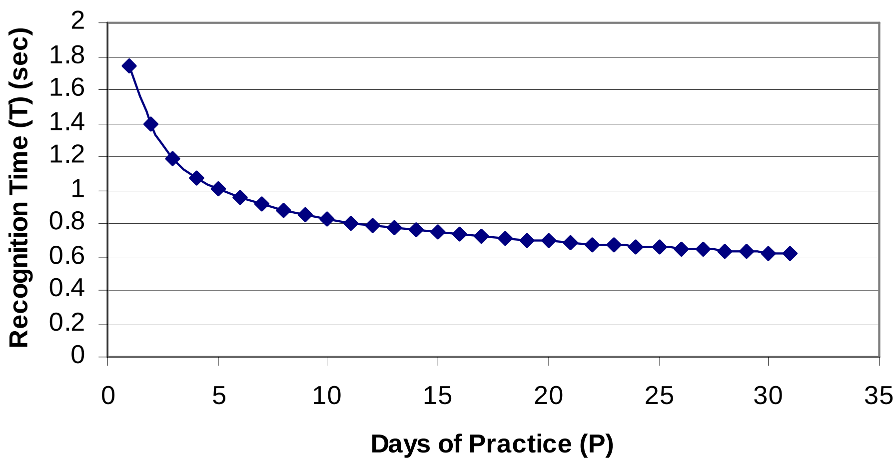

Figure 1: Power Law of Learning Over increasing days of practice, a simple recognition task (time required to recognize sentences) requires ever decreasing amounts of time (as found in Anderson, (2005)).

Skill completion - or task completion - time is typically modeled in terms of learning curves (Ebbinghaus, 1913; Anderson, 2005; Sikstrom and Jaber, 2002; and Wixted, 2004). Figure 1 illustrates the Power Law of Learning (Pirolli and Anderson, 1985) derived from empirical studies that appear ubiquitously in cognitive psychology texts (e.g. (Anderson, 2005)).

Time delay in between periods spent performing a task causes employees to forget. The rate at which forgetting occurs increases with task complexity and with simple failure to recall an item or procedure with some frequency (Jaber and Sikstrom, 2004). As with learning, forgetting can be modeled by a function based on a power law (e.g., Wixted, 2004; Wickelgren, 1974; and Ebbinghaus, 1913), e.g.: $R(t) = at^{-b}$ where t is time and a and b are scalars (see Figure 2).

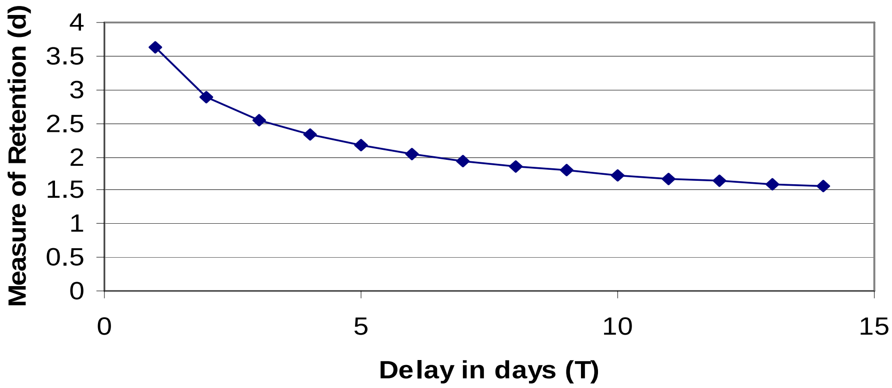

Figure 2: Power Law of Forgetting. Over time what is known decays at a negatively accelerating pace. (Wickelgren, 1975; Wixted and Ebbesen, 1991)

Most prior research on forgetting has focused on relatively simple tasks, such as list learning, where a participant is asked to recollect and recite memorized items from a list and, over time, begins to forget them (e.g., Anderson, 2005). Similar effects can also be seen in the recall and performance of complex skills (Ericsson and Charness, 1994), such as forgetting in a practicing physician, (Smith, 1978) or skill decay in cardiopulmonary resuscitation (CPR); (McKenna and Glendon, 1985).

We will maintain our focus upon the learning and forgetting of a complex cognitive skill (such as counterterrorism analysis rather than simplified list learning. In this next section, we further narrow our scope toward analyzing skill learning and forgetting by categorizing different skill types

Skill Classification

Not all skills are learned by individuals with equal speed. Dar-El et al. (1995) classifies skills in the four following categories: (1) highly cognitive, (2) mostly cognitive, (3) mostly motor, and (4) highly motor, as shown below.

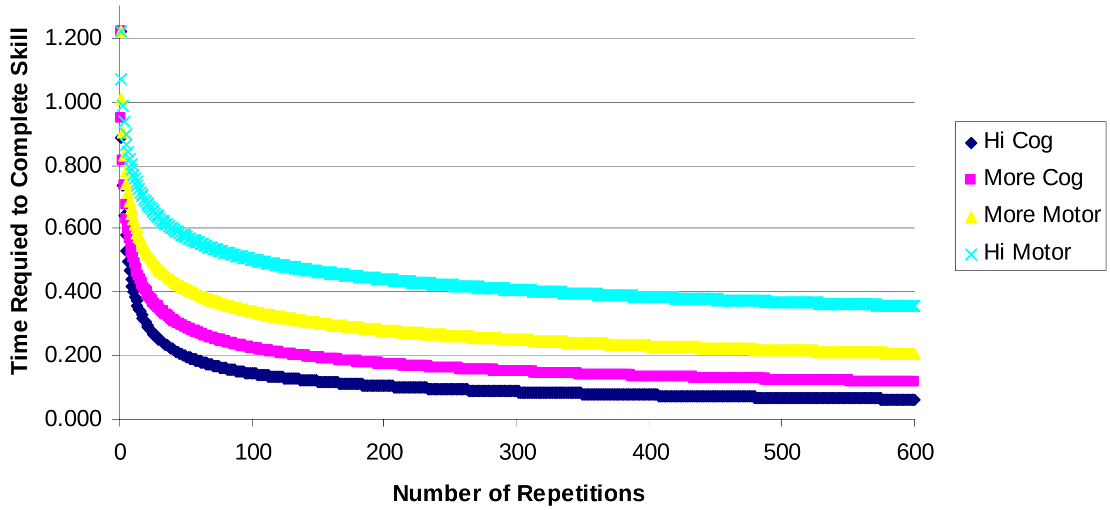

Figure 3: Learning Curves for Different Types of Skill (Source: Dar-El et al., 1995). As skills become increasingly cognitive vs. motor, the improvement in performance for a given number of repetitions is more pronounced and the skill level (the inverse of the time to takes to perform the task) asymptotes to a higher multiple of the initial skill level.

Figure 3 illustrates the learning rate differences among four classifications of skill. We anticipate that this classification will further our understanding of skill learning when combined with forgetting. Later, we will conduct an experiment whose empirical data will be plotted against these curves to attempt to classify the type of skill being conducted. We will attempt to combine and build upon these theories by combining learning and forgetting with skill classification to improve our ability to forecast knowledge, or skill level, over time. Our claims of theoretical and practical contribution will be assessed by comparing our empirical findings from the AROUSAL exercise to the Dar-El learning curves above.

We next discuss research about organization level skill loss and gain as we anticipate that individual learning and forgetting rates will have organization-level effects.

Organizations

There is a large body of literature on information flow in organizations, going back to the pioneering work of Herbert Simon and James March in the 1950's (Simon and March, 1958). These efforts were built upon though increased exploration about how organizations learned through "encoding inferences from history into routines that guide behavior" (Levitt and March, 1988, p.320), by "knowledge that becomes embodied in the organization's technology" (Epple, Argote, and Devadas, 1991), or by measuring decreasing costs of production through learning-by-doing (Wright, 1936; Goering, 1993; and Benkard, 2000). However, the corresponding literature on knowledge flow in organizations is still emerging (e.g., Levitt et al., 1999, Nonaka, 1994, and Nissen, 2006) and pays little attention to the impact of organizational forgetting.

Schreiber and Carley (2004) using CONSTRUCT, as well as Reagans et al. (2005), have modeled individual knowledge as both cognitive and *transactive.* Transactive knowledge refers to the "meta-knowledge" of where or with whom different kinds of knowledge reside (Wegner, 1987). They seek to determine the impact that database use and data type have on organizational performance in terms of levels of group interactions and knowledge sharing. Our research has a similar goal, but will take a different approach by considering the deficits of forgetting. We seek to improve organizational project outcomes by accurately predicting the impact of individual learning and forgetting on project duration, cost, rework volume and quality risk.

Researchers have also analyzed and attempted to explain individual and organizational levels of information and knowledge flows (Simon, 1950; Argote, 1999; and Nissen, 2006). Knowledge, seen as *inflows* and *outflows* (Dierickx and Cool, 1989), is another method of analysis. These inflows and outflows are metaphorically viewed as water entering and exiting a *bathtub*. In this sense, the level of water is viewed as the level of available knowledge to the organization and the amount of water entering and exiting the bathtub is seen as knowledge improvement and knowledge lost respectively.

We consider that the flow of an organization's knowledge can be modeled through learning and forgetting among its individual participants. And when those individuals frequently perform their skills, there is no loss of knowledge and potentially some growth. When skills remain unused or dormant, knowledge slowly erodes over time. We conceptualize that the current level of knowledge for an individual is demonstrated though the required time for the individual to accomplish a specific skill-based task. We consider that as knowledge level improves, a concomitant increase in task processing speed will also occur. We now envision a method to advance from qualitative analysis to quantitative analysis of organizational knowledge flow. We will analyze the organizational effects of individual learning and forgetting. We intend to use organization simulation (POW-ER 3.2) to demonstrate the impact on project duration and process quality as dynamic levels of individual participants' knowledge level occur.

Our research questions are:

1. How can we predict the effect of individual learning and forgetting on organizational (or group) performance?
2. How can we model an organization whose individuals learn and forget?

Points of Departure

Previous attempts to model and simulate Edge vs. Hierarchical organizations using OrgCon (software created by Burton and Obel, 1995) and SimVision (Nissen, 2005; Orr, Nissen, 2006) were conducted to determine organizational *misfits* when applying Edge vs. Hierarchy organization structures to given tasks and contexts, but did not involve agent learning or forgetting. In these studies, agents were assigned fixed skill sets and each organizational structure was imbued with different simulation parameters. For example, Functional Exception Probability (FEP) was set to 0.1, as well as high centralization and formalization with low matrix strength for the Hierarchy case; and FEP was set to 0.2 with low centralization and formalization, and high matrix strength, for the Edge case (Nissen, 2005).

It was determined that under Industrial Age conditions, Edge organizations performed slightly better than their Hierarchy counterparts for project length (223 vs. 227 days) and cost much less (9B vs. 12B dollars), yet project risk was much higher (.78 vs. .36). Under 21st century conditions, it was determined that for project duration and cost, Edge organizations performed much better than Hierarchies (235 vs. 314 days) and (10B vs. 16B) while relative project risks remained unchanged (.78 vs. .36) (Nissen, 2005p. 16).

Our research, instead, keeps simulation parameters such as FEP, matrix strength and centralization, equal across the two organizational forms, in order to isolate any differences in organizational performance between Edge and Hierarchy forms based solely on structural differences in authority relationships and information flows. In addition, we incorporate learning and forgetting micro-behaviors for participants in the two organizational forms to assess their impact on performance, again using equal parameterization.

Learning with Forgetting

Few studies have been published illustrating the gains and losses to projects as their employees learn and forget skills over time, or as they turn over during and between projects. A notable exception is (Ibrahim, 2005). There have also been few attempts to determine how to manage this knowledge in terms of interventions such as mentoring, training or OJT (listed from smallest to greatest levels of available research). For example, Carley and Svoboda (1996) and Carley (2001) model individual learning computationally, and model organizations that can *adapt* (*hire, fire, redesign,* and *retask*) toward an increasingly optimal design to achieve maximum organizational performance. Carley also models the reduced impact of individual knowledge on performance with organizational structural changes.

There is a nascent trend in the literature to view knowledge as a supply chain or knowledge chain (Holsapple and Jones, 2004 and 2005). This line of research to date is qualitative, using only natural language descriptions. Kim (1993) also seeks to link individual learning to organizational learning via natural and metaphorical thinking and examples. However, Kim's efforts do not extend to quantifying the effects of individual learning and forgetting on project outcomes. Our contribution will be to extend this portion of the literature by moving beyond the current natural language descriptions and toward a more quantitative computational perspective that has the potential to predict and ultimately manage knowledge inventory optimally in project teams. We seek to improve organizational project outcomes by determining the specific, quantitative impacts of individual learning and forgetting on organizational performance.

Ramsey et al. (2006) extended POW-ER to add learning and forgetting capabilities. During 2005-06 we obtained theoretic learning and forgetting rates from Cognitive Science literature (MacKinnon et al., 2006). We anticipate that each agent's dynamic, skill completion time speed will have far-reaching implications throughout the organization that will directly affect expected project cost, length, rework and project risk. Thus, we wanted to calibrate these learning and forgetting rates against modern organizational knowledge-work tasks for use in POW-ER. Once these calibrated learning and forgetting behaviors rates are implemented in POW-ER, we can more confidently begin to quantify how dynamic, individual knowledge will affect performance outcomes at the organizational level.

Current Research

Calibrating Learning with Forgetting

We began by considering how we might measure dynamic knowledge level among individuals. It seems that one clear measure of knowledge level is the time required to complete a complex task. We selected a business case simulation, entitled AROUSAL, where 31 students were asked to provide quarterly individual functional plans as well as integrated company business plans by choosing from among an array of possible managerial interventions. The four functional roles in each team were: marketing-sales, operations, human resources, and finance. Each participant was randomly placed in a four-person group and given one of these roles to perform. (One group consisted of only three participants; its data are not included in our analysis.) Each participant was directed to develop his/her individual quarterly functional business plan and recommended set of interventions. Each group was then directed to convene to integrate these plans and choose coordinated interventions for the company. Integration was non-trivial because each role competed for limited group resources. For instance, each group's budget for each period had to be divided among investments in ongoing operations, marketing expenses, hiring new employees and writing proposals (bids) for new construction jobs.

The simulation ran for 8 quarters, during which we recorded the time taken by individuals to develop their functional plans and the time taken by groups to develop their integrated plans. The first quarter was used to provide the players with training in how to input interventions and analyze outputs, so we have not included data from this quarter in our analysis. After 4 quarters, the groups were asked to stop playing and resume some time later, approximately 4 days, at their discretion. This delay introduced an opportunity for us to measure "forgetting" of previously acquired skills in playing each role.

Next, we show how our data on individual and group task durations over time compare to a set of four learning curves for different kinds of skills: highly cognitive, mostly cognitive, mostly motor, and highly motor (Dar-El et al., 1995). Our AROUSAL data were normalized against the Dar-El data based on the time for the first iteration. Normalized predicted durations for each period from our "learning and forgetting-enabled" POW-ER 3.2 simulation model of the AROUSAL exercise are plotted on the same graph.

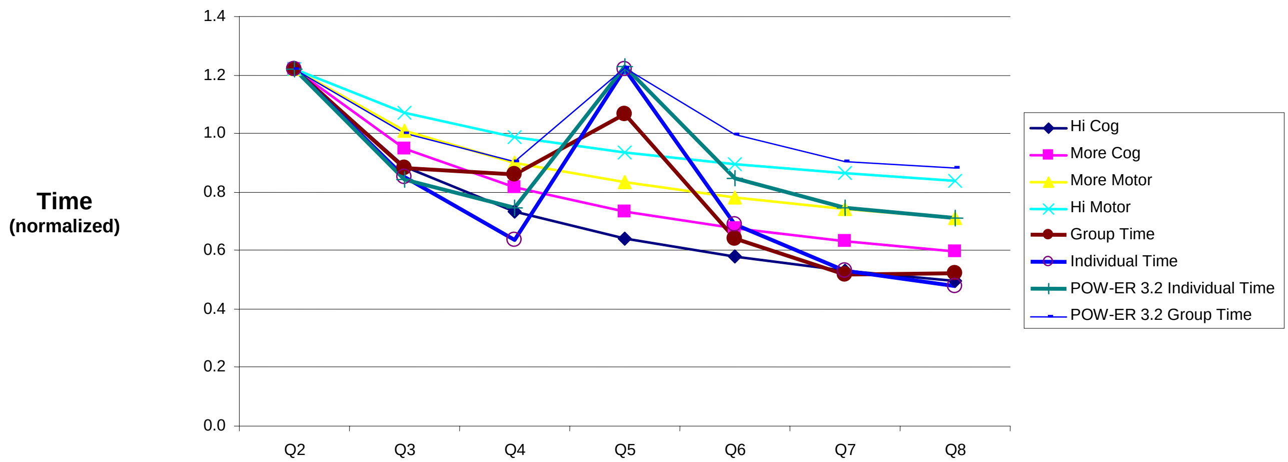

Figure 3: Dar-El et al. Learning Curves vs. Normalized AROUSAL Individual and Group Learning Rates and POW-ER 3.2 Predicted Durations Over Multiple Trials. These data show the effects of cognitive learning, the effects of forgetting caused by a delay after trial Q4, plus the re-acquisition of skill following the delay. Note the fit between the individual and group AROUSAL data vs. the Dar-El "Hi Cog" curve. The POW-ER 3.2 predicted durations for individual time initially fit the Dar-El "Hi Cog" curve well, but do not catch up with the recovery in empirical AROUSAL durations after the delay; the POW-ER predictions for group durations exhibit slower learning rates, comparable to Dar-El's "More Motor" curve.

Our data demonstrate an excellent fit to Dar-El's et al. (1995) findings for "Highly cognitive" skill learning as shown in the averaged processing times for both individual and group learning and forgetting. The individuals and groups each exhibited learning behavior in their skill completion time during the first three quarters. (Recall, quarter 1 data is not included because it is a training trial.) Groups and individuals each showed a marked increase in required time for the quarter 5. This seems due to the 3 to 4 day delay between performing the first three and second four sets of simulation runs. The increase in time for the fifth quarter indicates the level of skill decay, or forgetting, that occurred as a result of the delay.

We note that our empirical data plots along the "cognitive skill type" curve for both the individual and the group data for the second and third quarters. The average time increase for AROUSAL groups during the fourth quarter is anomalous; it may have occurred due to the groups' growing interest in performing well in the simulation and taking more time to integrate their individual plans. Quarter 5 shows an increased time requirement for both individuals and groups, with the individuals' percentage time increase being significantly higher than the groups'. This time increase follows the multi-day break taken by all groups between sets of simulation runs. Forgetting seems to occur less drastically among the groups than the individuals as seen in figure 3, yet both the individual and the group durations return quickly to approximate their original trend curve for learning of cognitive skills. In replicating the theoretic findings of Dar-El et al., we provide compelling evidence to validate the Dar-El "High Cognitive" learning rates that we had embedded in POW-ER 3.2 for individual learning of cognitive skills.

The POW-ER 3.2 predicted individual durations initially fit the Dar-El "Hi Cog" curve well, but do not catch up with the recovery in empirical AROUSAL durations after the delay. The relatively good fit between the individual empirical data with the POW-ER 3.2 predicted individual learning and forgetting curve, supports our claim of initial calibration and validation for the learning behaviors in the POW-ER 3.2 model. The POW-ER predictions for group durations exhibit slower learning rates, comparable to Dar-El's "More Motor" curve. This suggest that we slightly re-calibrate POW-ER for more rapid learning following delay; and that we re-calibrate POW-ER

micro-behaviors to try to get group rates to approximate individual rates more closely, per our empirical findings.

The amount of skill loss caused by delay between runs 4 and 5 was found to be proportional to the length of the delay. For every day of delay that groups waited to commence the final 4 quarters, the time required for the groups to integrate their business plans grew as shown below.

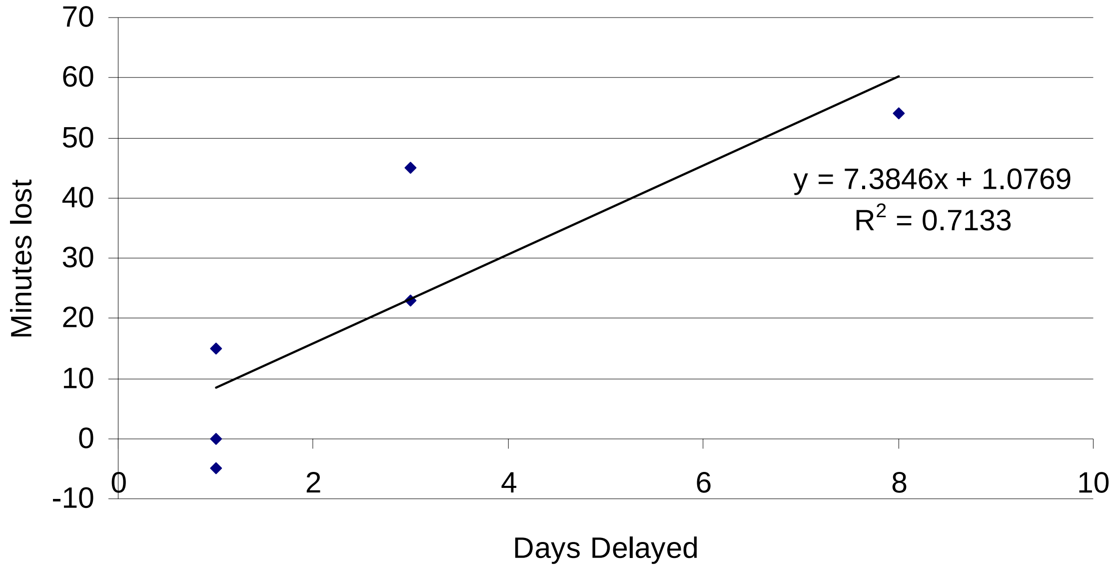

Figure 4: Forgetting Correlation for Aggregated Group Data which shows the relatively high correlation between time lost in completing the skill after a given delay in time.

From the regression trend line in Figure 4, we note that approximately 7.4 minutes are lost for every day of time delay between tasks (R^2=0.7133). The group data indicates that the group skill requires 39 minutes on average to accomplish. From this, we infer that for every day in delay, each group loses approximately 19% of its skill in terms of average processing speed (7.4/39 minutes). (One group showed skill improvement after a one-day delay which resulted in negative time lost. Data from another group is not included due to their taking two breaks in delay instead of one.) We again show compelling evidence to support our use of this aggregated finding to calibrate forgetting of cognitive skills in our POW-ER model because of this high correlation found between time delay and the fraction of skill lost.

We next modeled the AROUSAL exercise with and without learning by the POW-ER 3.2 computational agents. The AROUSAL exercise is typically conducted in about 90 minutes depending on the team's ability. The smallest "clock-tick" in POW-ER's discrete event simulation framework is currently one minute, and exception handling times, waiting time-outs for "delegation by default" decision making, and other simulation parameters were originally developed and have been extensively calibrated for tasks with durations from one day to several days. Ultimately POW-ER will be calibrated, and its minimum clock-tick reset, to allow for tasks of arbitrary length. In the meantime, we scaled the input measures up from minutes to days and scaled down and output measures back to minutes in making the comparisons between simulated *vs.* empirical data for the two organizational forms.

Table 1 compares our empirical and synthetic experiment findings.

Table 1. AROUSAL: Empirical Data vs. POW-ER Model Output Individual and group duration data shown were normalized for the Empirical data and the POW-ER model in the "without learning" case. In the "learning-enabled" case, the individual empirical and the POW-ER data differ by 1.8% and the group data differ by 0.5%.

Metric	Individual Data		Group Data	
	Empirical	**POW-ER 3.2**	**Empirical**	**POW-ER 3.2**
Summed individual durations (based on initial period, without subsequent learning)	161 days	161 days	406 days	406 days
Duration (with learning)	106 days	103 days	235 days	233 days
Percent Savings from Learning	34.2%	36.0%	42.1%	42.6%

Table 1 compares our empirical with our synthetic output at both the individual and group levels. Row 3, columns 2 and 3, contain the required work (161 days) of each individual both empirically and as modeled using POW-ER 3.2. Row 4, of columns 2 and 3, illustrate the reduced duration of the work as a result of learning by the individuals. Row 5 contains the percent savings, both observed and output from the model, that result from learning. Columns 4 and 5 include the same comparisons taken at the group level.

The 161 *days* shown for the duration for the empirical data was determined by multiplying the original average exercise time required (23 days), by the number of quarters to be played — in this case seven — i.e., (23 * 7). The duration with learning, shown in the next row, was developed by observing student teams who performed each subsequent quarter requiring less time than the previous quarter, with the exception of the quarter that followed the production break between Q4 and Q5. The average total time required by the individuals was 106 days, or a 34.2% savings resulting from learning. Groups required 58 days each quarter, for a total of 406 days — (58 * 7). Their duration from learning also caused a decrease which totaled 233 days.

The POW-ER model began with the same required time yet with the learning and forgetting micro-behavior embedded, forecasted a savings of 36.0% among the individuals and 42.6 % among the groups over the seven quarters. The difference between the empirical data and the model output in the learning case may be accounted for by differences among teams of individuals.

The following section illustrates POW-ER 3.2 predictions for individual quarterly durations followed by group durations in the AROUSAL exercise.

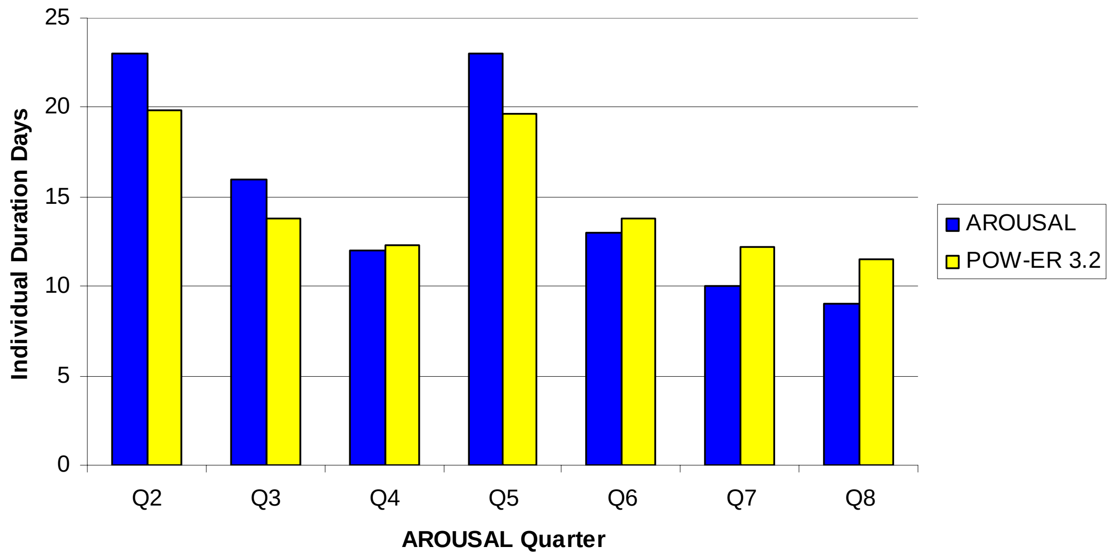

Figure 5: POW-ER 3.2 Predicted Individual Durations for Each Quarter which shows very high correlation between the empirical and synthetic output.

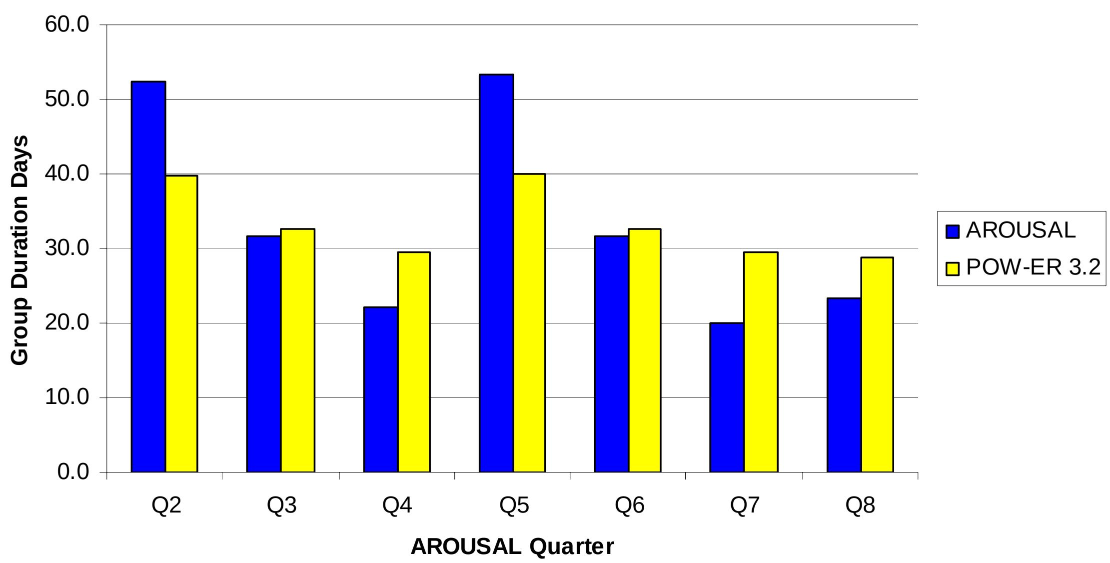

Figure 6: POW-ER 3.2 Predicted Group Durations for Each Quarter which also shows relatively high correlation between the empirical and synthetic output.

The group durations fit the relative trend of the empirical data. We attribute the difference to relative differences among teams. From these results, we claim that the learning and forgetting micro-behaviors in POW-ER are qualitatively validated and tentatively calibrated to reasonable rates of individual learning and forgetting for cognitive tasks at both the individual and group levels.

We next discuss our methodology to further refine our calibration and validation of POW-ER 3.2 by using more empirical data obtained through another exercise entitled “ELICIT.” This effort serves our purpose of refined calibration and validation but also, offers the opportunity to

compare how two different organizational forms differ in their performance when their individuals learn and forget. We will provide an overview of ELICIT, followed by a description of our modeling efforts.

POW-ER Model: ELICIT

Exercise Overview

The ELICIT exercise was created for experimentation in command and control settings to compare alternative organizational forms (e.g., Hierarchy vs. Edge). ELICIT simulates an anti-terrorist organization that must collectively analyze a series of “factoids” —simple statements related to an impending terrorist attack obtained via (unspecified) counter-terrorism intelligence sources—distributed to members of the organization in order to specify the impending terrorist attacks precisely in terms of: who, what, when, and where. We simulate ELICIT initially without individual learning and forgetting using data from three trials conducted in June 2006. We then embed agent-based learning and forgetting algorithms (calibrated from our AROUSAL exercise) in the agents in our ELICIT POW-ER model to predict and compare the differences in organizational performance between Edge and Hierarchy organizations, with and without individual learning.

ELICIT is played using a set of instructions for either the Hierarchy or Edge organizational form (Parity Communications, 2006). Players in the Hierarchy form, for example, are instructed that they have each been assigned to a specific team of four players each of whom is to resolve a specific part of the terrorist attack plot. The team names are: Who, What, When, Where. Each of these teams has a leader assigned who coordinates information with the overall Coordinator. The Edge players are not assigned to specific teams, nor is there an overall Coordinator.

Each member of both the Hierarchy (H) and Edge (E) teams receives four factoids in total to assist in their identification of the terrorist threat. They are distributed two to every player initially, followed by two additional distributions (or *waves*) of one factoid each time. The initial wave of factoids commences shortly after the game commences and occurs again at five-minute intervals (at time: 0, 5, and 10 minutes respectively). There are differences in how these factoids can be communicated among the players. Hierarchy players may only *post* to and view from their own team’s website, whereas Edge players can *post* to and view from any team’s website. Any player in either organizational form may however, *share* their *factoids* with any other player. In the Hierarchy form, the Coordinator is the only player who may view all the team’s websites. The Coordinator may then decide to *share* particular and appropriate factoids with a specific Hierarchical team. Each team is comprised of 17 players who may share their knowledge using only electronic methods via various electronic channels as explained above. We therefore hypothesize that a bottleneck of information flow can occur as a result of requiring the Hierarchy Coordinator to view and then share other teams’ factoids.

Each player is then given up to 60 minutes to identify the terrorist threat correctly by combining multiple and corroborating factoids that seem to convey the most plausible and logically correct scenario. Each player may identify all or part of the terrorist threat at any time during the exercise. The exercise concludes when all players have correctly identified the terrorist threat.

Modeling Details: Hierarchy vs. Edge

We begin with a clean slate approach, taking into consideration the agents and the tasks they must complete. Agents of similar abilities and with similar task assignments were modeled in POW-ER 3.2. Multiple agents may be grouped together if assigned to accomplish the same task or tasks. Dissimilar agents of different skill levels must be assigned separately to tasks. We next create tasks for the agents, or groups of agents, such as coordinating or analyzing. The Overall Coordinator in the Hierarchy organization is assigned the task of “overall coordination,” the team leaders “coordinate” their individual team, and team members “analyze” their factoids. Assignment connection arcs are used to identify task responsibility. Each successive task is connected in series until the simulation is finished. “Communication links” are added to show

who has the ability to communicate with whom. "Knowledge links" are added to indicate who has access to partially or fully shared knowledge repositories such as synthetic websites. This style of modeling follows a reasonable fit to the ELICIT methodology of the exercise. ELICIT tasks are discretely assigned to each individual or team and are continually worked upon until each assigned task is accomplished. The C2 processes of organizational knowledge sharing are also effectively reproduced using POW-ER 3.2 links.

In the Edge form there is no assigned coordinator and so one player was added to "Team A" in our model to ensure the models remained equal in terms of available Full-Time-Equivalent staffing. We also ensured that each overall team was assigned an equal amount of work. The POW-ER models of the Hierarchy and Edge organizations used in our POW-ER 3.2 model of the ELICIT exercise are illustrated in figures 2 and 3 below.

All agents for each organizational structure were given the skill level of "low." This level can be allowed to increase dynamically as the skill is used to perform tasks or can decrease, as the skill remains dormant. It can also be kept fixed for the duration of the simulation by disabling learning and forgetting in our model. An initial skill designation of "low" provided us with a noticeable difference between successive runs of the same work processes when agent's skill either increased or decreased.

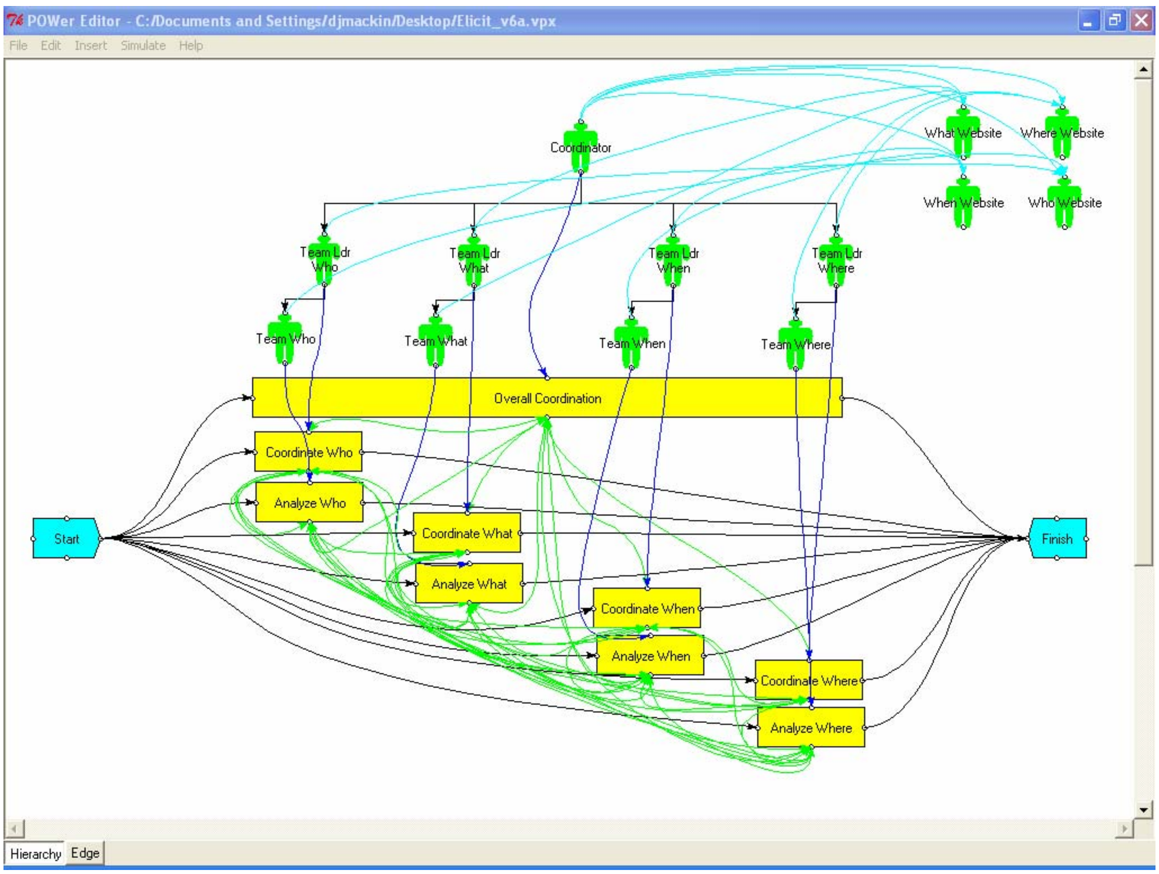

Figure 7: Hierarchy Organization of the ELICIT game showing communication links between the task boxes as well as knowledge links between all agents and the ELICIT websites. An overall coordinator with a two-level organization is also modeled.

ELICIT game players can "pull" knowledge from synthetic websites to refine their identification of the threat scenario as discussed above. We envision an opportunity to take advantage of a unique capability in POW-ER, that does not exist in SimVision, by modeling

knowledge networks using knowledge links (shown between agents and websites) that allow a player's (agent's) functional exceptions to be handled by the highest skilled agent (a website in this case) to which that player is linked. The use of knowledge networks allows agents to seek out information from agents (including online knowledge bases or web sites) of higher skill/knowledge, when such resources are available. This method of meta-knowledge or knowledge networks, although not an exact fit for the kinds of knowledge processing that occur in an ELICIT game, seems a reasonable approximation. This methodology represents a reasonable approximation for a possible future version of ELICIT if the game were to allow for a "system of reputation" or source verification to be used by future players.

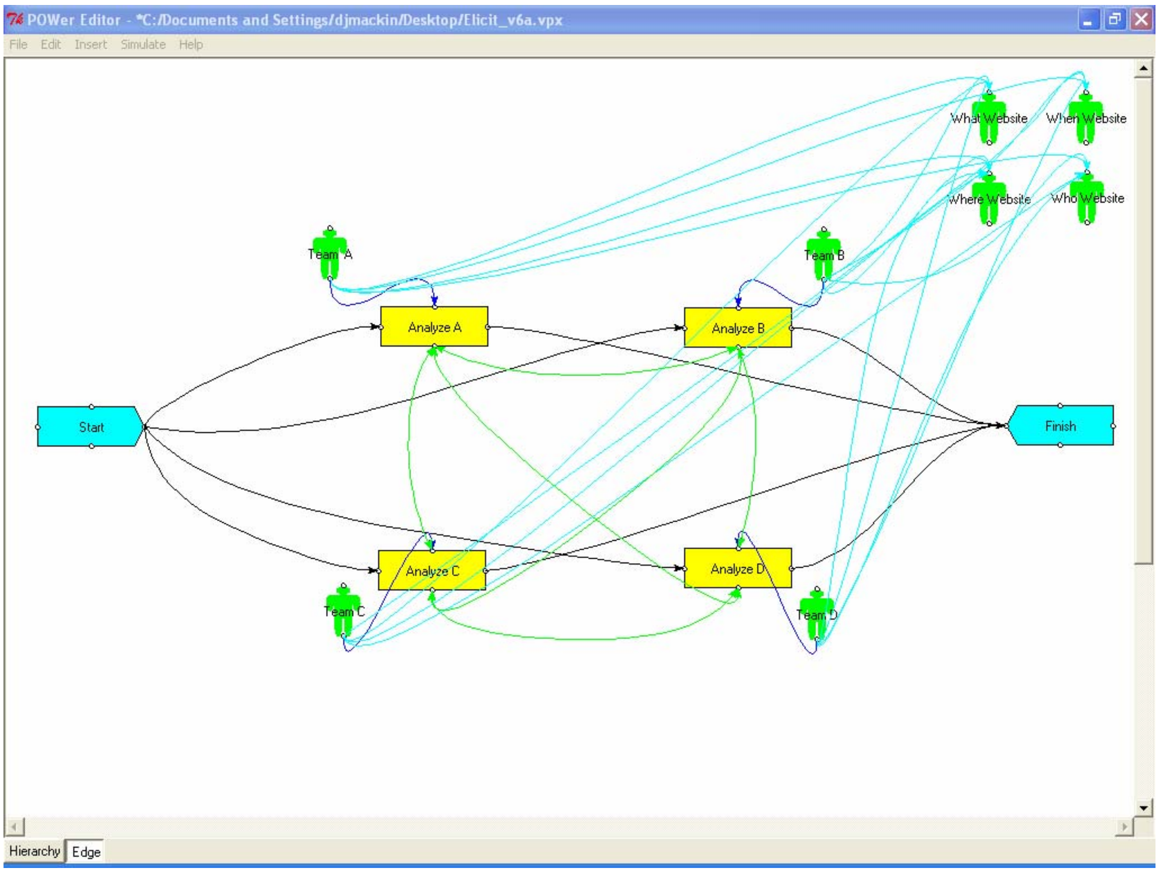

Figure 8: Edge Organization of the ELICIT game showing direct communication between all tasks (boxes) as well as knowledge links between agents and synthetic websites, within a flat, "Edge" organization.

In the Edge case, all the players were assigned the "team member" role as a means of modeling equal decision making responsibilities, whereas in the Hierarchy case, the Overall Coordinator is assigned the "Program Manager" role. The team leaders are assigned "Leader" roles and the remaining agents are assigned team member roles to account for their decreased decision making responsibilities. As in the AROUSAL model, we scaled our assigned work within the POW-ER model in *days* although the ELICIT game is typically played for about 60 minutes depending on the protocol involved. We again directly translate inputs and outputs back and forth from minutes to days and back to minutes for analysis.

POW-ER also has the ability for the user to invoke and control certain simulation parameters such as: communication probability, noise probability, functional error probability, and project exception probability and many others. We set the communication probability to 0.6 for both the Hierarchy and the Edge forms within POW-ER 3.2 to account for a relatively high level of required communication and because we wish to determine the difference resulting the two organizational

structure forms without increasing (or decreasing) other model parameters for either organizational form. We set the functional exception probability in each case to 0.5 to represent relatively high amounts of knowledge processing activity within each organizational form. All other parameters remained at their default values and were equal between the two organizational forms.

Results

ELICIT Empirical Data

The fully instrumented data output which recorded each player's actions, enabled our analysis of the frequency of knowledge (*factoid*) sharing via synthetic websites, and the occurrence of correct responses regarding target identification in terms of *who*, *what*, *when*, and *where*. The following graph illustrates the quantitative difference between Hierarchy and Edge organizational forms though the comparison of students' accurate answers given during each ten-minute interval of each game. Data from three rounds of the ELICIT game are available at present. Two of these rounds were conducted using a Hierarchy organization. The hierarchy data report the average of the two ELICIT rounds played in the "hierarchy" structure. The other round implemented an Edge organization.

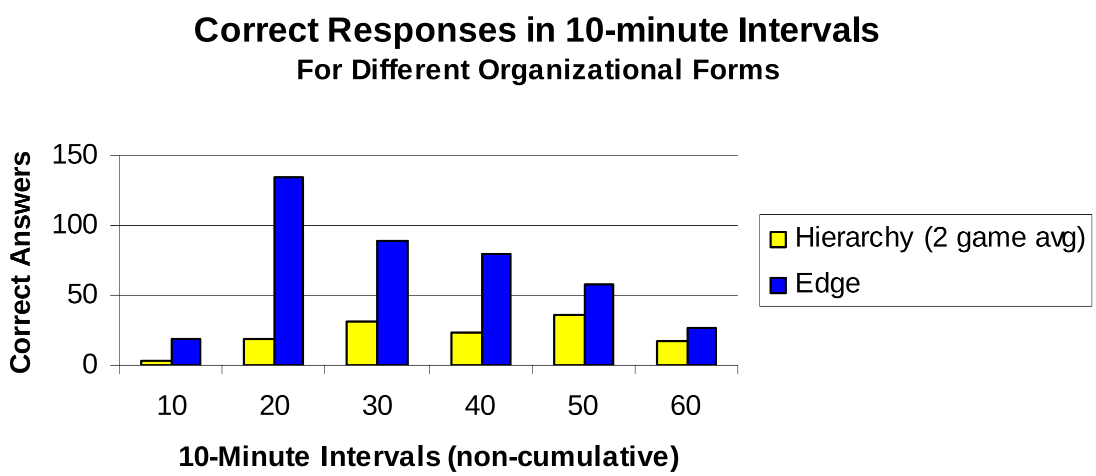

Figure 9: Hierarchy vs. Edge Organization empirical output from the ELICIT game showing the total number of correct answers given by all members of Hierarchy or Edge organizations during successive ten minute intervals.

The numeric data, included in Appendix A, also indicate that the Hierarchical organizations never produced a completely correct response to the terrorist threat. The Edge organizations produced completely correct responses at minutes: 16, 17, 18, 19, 20, 21, 32, and 49 after the exercise was begun. The empirical data illustrated above reveal a substantial difference between the two organizational forms in terms of the frequency of agent's correct answers produced over time.

The small number of games played limits any claim of statistical significance. We will therefore search for reasonable conclusions about the two organizational forms that arise from the empirical findings. These initial conclusions will guide our assessment and initial veridicality of our model output. We anticipate that future ELICIT rounds will provide us data for more rigorous statistical testing and increase the reliability of our conclusions.

This next section uses the evidence above to qualitatively compare POW-ER 3.2 model output. We use the learning and forgetting algorithms developed from AROUSAL to model the ELICIT Edge and Hierarchy organizations. We analyze the model output to test whether we can begin to validate the learning behaviors in POW-ER qualitatively using the empirical ELICIT data, and show that Edge organizational performance may surpass Hierarchical performance as a result of individual learning.

POW-ER Model Predictions

Table 2 below provides a comparison of average POW-ER model predictions from 1,000 simulation runs based on the ELICIT exercise, using the Hierarchy vs. Edge organizational forms, assuming no individual learning occurs during the exercise. We conducted these runs to set a reasonable baseline of organizational performance without invoking our learning and forgetting algorithm.

Table 2. POW-ER Output: Hierarchy vs. Edge Performance (without learning) Simulated duration is qualitatively comparable to empirical results in terms of the timing and frequency of correct answers among the two organization forms. Computation of duration and work effort was conducted in days, which are translated to minutes in the student game as explained above. The average of 1000 runs is listed first with standard deviations in parentheses. Metrics that are statistically significantly different for the two forms are marked with an asterisk and the result of the "higher performing" structure in each row is shown in bold font.

Metric	**Hierarchy** Mean (Std. deviation)	**Edge** Mean (Std. deviation)
Duration*	96.4 (8.0) days	**90.6 (10.1) days**
Coordination*	405.0 (13.2) days	**289.6 (11.9) days**
Rework	276.7 (19.6) days	**274.9 (25.5) days**
Functional Exception Work	**1373 (n/a) days**	1378 (n/a) days
Total Work*	2280.3 (29.6) days	**2170.9 (32.5) days**
Functional Risk	**.798 (.012)**	.801 (.015)
Process Quality Risk	.475 (.004)	.475 (.005)
Cost*	1802.0 (23.5) K	**1737.1 (26.0) K**

In the three student team runs of the ELICIT exercise, play was terminated after 60 minutes without either team having "completed" the exercise. That is, neither team converged to a correct identification of all four parameters of the anticipated terrorist plot that was to be interdicted, although some players had made fully or partially correct identifications at various points during the exercise. Thus, any attempts to claim calibration in terms of even "qualitative consistency" are quite tentative at present.

The POW-ER predictions from these initial prototype models and our first three sets of empirical ELICIT data show plausible qualitative consistency with the empirical data for *duration*, compared with the three rounds of the ELICIT game. For instance, it seems likely that from the empirical study that the Hierarchy game would have required much more time for the players to have correctly identified the plot, whereas seven of the student Edge players had already correctly identified all parameters of the terrorist plot at the sixty minute point (see Appendix A). The other POW-ER output metrics listed also appear to indicate qualitatively correct differences between the outcome metrics for Hierarchy and Edge organizational forms, based on the theoretically claimed advantages of Edge Organizations as well as prior computational modeling experiments described in the first section (Orr and Nissen, 2006 and Nissen, 2005).

ELICIT Model with Learning and Forgetting

We next took the same POW-ER models and sequentially executed them three times in succession using no gap between rounds one and two, and a five day gap between rounds two and three to allow for learning and forgetting to occur. Our simulation findings are shown below.

Table 3. POW-ER Output: Hierarchy vs. Edge with and without Learning and Forgetting. The "No Learning" baseline results from Table 2 are multiplied by three to compare with the three trials that have learning and forgetting enabled. All "no learning" results are the mean of 100 runs shown with the standard deviation in parentheses. Metrics that exhibit statistically significant differences between the "With learning and forgetting" cases for Hierarchy vs. Edge are denoted by an asterisk.

Metric	**Hierarchy (3 Rounds)** Mean (Std. deviation)		**Edge (3 Rounds)** Mean (Std. deviation)	
	No learning	With learning and forgetting	No learning	With learning and forgetting
Duration (days)*	289.2 (8.0)	244.9 (14.9)	271.8 (10.1)	210.0 (20.5)
Coordination (days)*	405.0 (13.2)	454.9 (15.4)	289.6 (11.9)	313.0 (11.8)
Rework (days)	276.7 (19.6)	276.8 (20.4)	274.9 (25.5)	274.2 (27.9)
Functional Exception Work (days)	1373 (n/a)	1378.3 (n/a)	1378 (n/a)	1373.5 (n/a)
Total Work (days)*	2280.3 (29.6)	2338.2 (31.8)	2170.9 (32.5)	2193.7 (36.0)
Functional Risk	.798 (.012)	.799 (.012)	.801 (.015)	.801 (.016)
Process Quality Risk	.475 (.004)	.474 (.004)	.475 (.005)	.475 (.005)
Cost ($K)*	1802.0 (23.5)	1297.7(46.3)	1737.1 (26.0)	1191.9 (53.1)

The POW-ER 3.2 ELICIT model provides many kinds of outputs as illustrated above. We will continue to focus on project *duration* to maintain consistency and verifiability. The model output indicates that the expected duration of the ELICIT game for three rounds (two rounds in succession followed by a break of five days followed by the third round) is highest for the Hierarchy organization when learning is not invoked. The Hierarchy organization, with learning and forgetting invoked, demonstrates a statistically significant decrease in required duration. The Edge organization also demonstrates a statistically significant decrease in duration when learning and forgetting is invoked. We find also that the Edge organization performs better than the Hierarchy organization when compared in the simulation runs with (or without) learning. This matches the empirical ELICIT data for these three runs of the exercise. This is in line with our finding that Edge organizations are predicted to perform better than Hierarchical organizations when learning is present — and Edge organizations learn more rapidly!

For external validity, we compare expected ELICIT game lengths by dividing the duration by three. This reveals average game lengths of approximately 96.4 and 81.6 minutes in the case of the ELICIT Hierarchy organization without and with learning respectively. This is a savings of approximately 15.4%. Edge game lengths are calculated to be 90.6 and 70.0 minutes for the Edge organization without and with learning respectively. This is a savings of approximately 22.7%. This suggests that when individuals learn in both structures, an Edge organization can improve its performance through reducing its required project duration by an additional 7.3% over a Hierarchical organization.

Figure 9 above supports the initial face validity of the POW-ER simulation model with learning and forgetting when applied to model this command and control synthetic task in two structural configurations. We will continue to validate and calibrate the ELICIT model as more empirical data becomes available and more is learned about the modeled organization differences.

Discussion

POW-ER is intended to model communications and exceptions for varying organizational forms. At present, the only forms of communication used in ELICIT are selective posts and shares, and there is no feedback to players on the correctness or otherwise of their “identification” assertions. The players do not receive nor respond to exceptions in the traditional sense of asking directly for assistance from a manager or knowledgeable peer, so we need to approximate this behavior through their communications to one another and their postings and reading of data from a game website. Moreover, as described above, neither the game nor the protocol for running this version of it provides a stopping point for teams that have already achieved correct answers.

This lack of agent feedback directly affects the outcome of the game. For example, looking at the available data for the Edge scenario (Appendix A), two players settled upon the correct answer early. Five other players also offered completely correct answers early in the game, yet rendered incorrect responses afterwards. The remaining ten players were correct on some of the answers at various points of the game yet failed to converge on the correct target identification.

Thus far it has been shown that humans perform better on the ELICIT game in the Edge structure as measured by our "number of correct answers per 10 minute interval" metric.

This study remains challenging as we attempt to leverage our ELICIT modeling efforts (with learning) based on limited empirical results. We will continue to refine our modeling and simulation of the ELICIT game in POW-ER 3.2 for both types of organizations, and look for opportunities to execute more empirical runs of ELICIT. This will provide further comparisons between the two organizational forms and further calibration and validation for POW-ER.

At this time we claim only face validity for comparability between the POW-ER model and the ELICIT exercise it is attempting to emulate. We claim to have obtained plausible qualitative agreement of model predictions for Edge vs. Hierarchy with learning enabled from one experiment, given the current implementations and limitations of both ELICIT and POW-ER. Ongoing comparisons will be made and analyzed between empirical ELICIT output and POW-ER simulation output for both a single trial (no learning) and multiple trials (with learning) of the ELICIT exercise. We will also conduct additional empirical validation experiments in which we model and simulate other work tasks to validate POW-ER with learning and forgetting agents. This will support ongoing calibration of the workflow model in POW-ER 3.2 and of the learning micro-behaviors that have recently been embedded in POW-ER. Analysis of our ongoing research will be reported at the conference.

Conclusions

This paper reports on our continuing efforts to understand the performance effects of Edge versus Hierarchy structural forms through cross-calibrated empirical micro-experiments and computational modeling experiments. This set of cross-validation experiments employs synthetic group experiments in two small group exercises and organizational simulations of Edge vs. Hierarchical forms in these two games with and without learning by agents, to cross-validate, calibrate and refine POW-ER parameters. We described our continuing steps in specifying the key variables that effect work flow, knowledge flow and organizational learning in both Edge and hierarchy organizations. The dynamics of individual knowledge gained and lost in organizations are captured and are thus able to extend our understanding of organizational learning through this extension to the POW-ER model framework.

These experiments provide new evidence for some of the predicted performance differences between Edge and Hierarchy C2 organizations both empirically and synthetically, and contribute toward an improved knowledge of performance effects for Power to the Edge C2 organization structures.

(Appendix B contains proposed changes to the ELICIT exercise that may enhance its veridicality as a means to test the effects of alternative organizational structures on team performance for C2 tasks, and to enrich our understanding of the impacts of participant's learning and forgetting rates.)

Future Steps

We intend to validate and calibrate POW-ER further as more ELICIT data become available, so that, through POW-ER, we may generate, model, and test novel hypotheses about Edge and other alternate organizational forms. We will also begin to develop representation and reasoning to model and simulate knowledge interventions such as training and mentoring to further explore the effects of such organizational knowledge flow investments.

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Appendix A – ELICIT game data

Data output from three previous student rounds of the ELICIT Exercise (17, 22, and 23 June 2006) are provided in the following three appendices. Correct responses in a single category are indicated by purple shading. Bright green shading indicates responses that are correct in every category.

17 June 2006 Data (Hierarchy Organization)

17-Jun-06			Identification Attempts						
			who	what	where	when			number
Time	Player	Team				Month	Day	Time	correct
3:06:34	Game Started								
3:10:14	13	When	Violet	high visability			5th	daylight	1
3:11:55	13	When	Purple	Train Station					0
3:15:06	5	What	violet						1
3:16:43	15	What		embassy					0
3:16:57	13	When	Purple	Train Station	Tauland				0
3:18:30	13	When	Purple	dignitary	tauland				0
3:20:35	5	What	violet	embassy					1
3:21:43	13	When		Dignitary	Tauland		5th	11:00am	2
3:23:09	6	When						11:00am	1
3:23:26	4	Where	Azur						0
3:24:05	13	When	Purple	Dignitary	Tauland		5th	11:00am	2
3:24:13	4	Where			Tauland				0
3:25:43	10	When	violet	financial summit	chiland				1
3:25:47	13	When	Violet	dignitary	Tauland		5th	11:00am	3
3:26:17	17	Who							0
3:26:54	6	When					5th		2
3:27:33	16	Who	violet	embassy	Psiland	April	5th		4
3:29:03	5	What	violet	epsilonland embassy	tauland				2
3:29:07	17	Who	The Lion	Tauland Embassy	Epsilonland	April	10th	1200am	2
3:30:23	13	When	Violet	dignitary	Tauland	June	5th	11:00am	3
3:30:36	6	When						11:00	0
3:30:48	10	When	violet	Train Station	tauland	June	5th	11:00am	3
3:31:27	10	When	purple	Train Station	tauland	June	5th	11:00am	2
3:32:05	13	When	Violet	embassy	Tauland	June	5th	11:00am	3
3:32:35	10	When	violet	financial summit	chiland	June	5th	11:00am	3
3:34:29	10	When	violet	financial summit	chiland	June	5th	11:00am	3
3:34:43	10	When	violet	financial summit	psiland	June	5th	11:00am	4
3:34:45	5	What	violet	Epsilon Dignitary	Tauland				1
3:35:47	13	When	Violet	embassy	Tauland	June	5th	11:00am	3
3:36:15	6	When	violet		psiland		5th	11:00am	4
3:38:48	16	Who	violet	financial institution	Chiland	April	5th		4
3:39:30	11	Where	Azur	Embassy	Epsilonland	August	22nd	05:00am	0
3:40:45	3	Who	brown	dignitary	Epsilonland	April	10th	8:00pm	1
3:41:46	10	When	violet	embassy	tauland	June	5th	11:00am	3
3:41:59	3	Who	violet	dignitary	Psiland	April	5th	12:00am	4
3:47:51	1	Who	Violet	Train Station	Tauland	April	5th		3
3:47:57	13	When	violet	embassy	Tauland	June	15th	11:00am	2

3:48:01	12	What	violet	embassy	tauland	June	15th	08:00am	1
3:48:48	10	When	violet	embassy	psiland	June	5th	11:00am	4
3:48:53	4	Where			Tauland				0
3:48:55	8	When	Violet	Coalition Embassy	Psiland	June	5th	11:00am	4
3:49:07	6	When			Psiland				1
3:49:16	9	Where	Coral	Dignitary	Psiland	June			1
3:49:27	2	When	Purple	financial institution	psiland	June	5th	11:00am	4
3:49:44	14	What	Purple	Coalition Embassy	Psiland	June	1st	5:00pm	1
3:49:54	8	When	Violet	Coalition Embassy	Psiland	June	5th	11:00am	4
3:50:14	10	When	violet	embassy	epsilonland	June	5th	11:00am	3
3:50:28	7	Where	Gold	financial institution	Chiland	anytime			2
3:50:37	17	Who	Violet	Tauland Embassy	Epsilonland	April	5	9:00pm	3
3:50:38	10	When	violet	financial summit	Psiland	June	5th	11:00am	4
3:50:55	10	When	violet	financial summit	epsilonland	July	5th	11:00am	3
3:51:04	1	Who	Brown	Train Station	Tauland	April	5th		2
3:51:22	5	What	Violet	embassy	Tauland	June	18th	1:00pm	1
3:51:31	2	When	Purple	financial institution	Psiland	January	5th	11:00am	4
3:51:50	15	What		high visability				during the day	0
3:52:43	12	What	violet	Epsilon Embassy	Tauland	june	1	8:00am	1
3:53:36	5	What	Violet	dignitary	Epsilonland				1
3:53:57	6	When	Violet		Psiland	April-December	5	11:00am	4
3:54:37	15	What	Violet or Coral	embassy	psiland			daytime	1
3:54:45	5	What	Violet	embassy	epsilonland	June		day time	1
3:55:22	3	Who	Violet	dignitary	Epsilonland	April	10	12:00pm	1
3:55:27	1	Who	violet	conference	epsilonland	april	10	2:00	2
3:56:23	5	What	violet	Epsilon Embassy	psiland				2
3:56:41	10	When	violet	The Lion	tauland	june	5	11:00am	3
3:57:15	12	What	violet	embassy	psiland	june	1	8:00am	2
3:57:39	16	Who	violet	embassy	Psiland	april	5th		4
3:58:47	10	When	violet		psiland	June	5th	11:00am	4
3:58:52	6	When		embassy					0
3:59:16	4	Where		Epsilonland's Embassy	Tauland				0
3:59:21	10	When	violet	embassy	psiland	june	5	11:00am	4
3:59:25	5	What	violet	embassy	psiland	June		during the day	2
3:59:56	11	Where	Azur	Espilonland Embassy	Tauland	August	22	3:00am	0
4:00:09	10	When	violet	dignatary	psiland	june	5	11:00am	4
4:01:10	1	Who	Azur	Conference	Epsilonland	April	10	12:00pm	1
4:01:52	10	When	coral	embassy	psiland	june	5	11:00am	3
4:01:54	1	Who	Azur	embassy	Epsilonland	April	10	1:00pm	1
4:02:21	1	Who	Brown	Embassy	Epsilonland	April	10	4:00pm	1
4:02:55	10	When	violet	buildings	psiland	june	5	11:00am	4
4:03:26	7	Where	Coral	Embassy	Psiland	work day		10:00am	1
4:03:34	1	Who	Brown	Tauland Embassy	Epsilonland	April	10	5:00pm	1
4:04:58	1	Who	Violet	Tauland Embassy	Epsilonland	April	10	4:00	2
4:05:33	10	When	violet	dignatary	psiland	june	5	11:00am	4
4:08:40	15	What	violet						1
4:08:43	2	When	Purple	dignitary	psiland	June	5	11:00am	3
4:08:44	15	What	violet						1

22 June 2006 Data (Edge Organization)

22-Jun-06		Identification Attempts						
		who	what	where	when			number
time	source				Month	Day	Time	correct
19:00:46	**Game Started**							
19:04:41	13	Violet	Tauland Embassy	Epsilon	April	5	11:00am	4
19:06:15	4	Violet group						1
19:06:23	13	Violet Group	Financial Institution	Tauland	April	5	11:00am	5
19:07:37	4		financial institution					1
19:07:50	4	violet group	financial instituion					2
19:07:50	8	the violet group	financial institution					2
19:08:13	16	coral						0
19:09:01	16			Epsilonland				0
19:09:16	16		International Conference					0
19:09:27	4	Violet group	financial institution		April	5		4
19:11:24	12	the coral group	embassy	Epsilonland	April	10	09:00am	1
19:11:38	8				April	5		2
19:12:32	13	violet group	financial institution	omega-lands	April	5	11:00am	5
19:13:26	16	violet						1
19:13:51	6	Violet group	embassy	Tauland	April	10	11:00am	3
19:13:58	16				April	10	11:00am	2
19:14:17	12	coral	embassy	epsilonland	April	10	11:00am	2
19:14:43	14	Lion	Financial Institution	Psiland	April	5	11:00am	5
19:14:45	6	Violet	Financial	Psiland	April	10	11:00am	4
19:14:46	12	coral	embassy	tauland	April	10	11:00am	2
19:15:01	8						11:00am	0
19:15:16	12	violet	embassy	epsilonland	April	5	11:00am	4
19:15:38	8				April	5	23:00	2
19:15:50	4	Violet group	embassy	Psiland	June	10	11:00am	3
19:15:53	11				April	10	11:00am	2
19:16:00	12	coral	embassy	epsilonland	April	10	11:00am	2
19:16:07	13	Violet Group	Financial Institution	Psiland	April	5	11:00am	6
19:16:18	12	coral	embassy	tauland	April	10	100:00:00	1
19:16:29	8				April	10		1
19:16:33	14	Lion	Financial Institution	Psiland	April	5	11:00am	5
19:16:35	13	Violet Group	Financial Instituation	Tauland	April	5	11:00am	5
19:16:37	12	coral	embassy	tauland	April	10	11:00pm	1
19:16:41	15	violet	financial institution	omegaland	April	5	11:00am	5
19:17:08	5	Violet	Financial Institution		April	5	11:00am	5
19:17:11	13	Violet Group	Financial Instituation	Upsilonland	April	5	11:00am	5
19:17:13	15	violet	financial institution	psiland	April	5	11:00am	6
19:17:38	13	Violet Group	Financial Institution	Chiland	April	5	11:00am	5
19:17:40	15	violet	financial institution	tauland	April	5	11:00am	5
19:17:47	2				April	5	11:00am	3
19:18:18	8			tauland				0
19:18:31	14	Lion	Financial Institution	Psiland	April	10	11:00am	4
19:18:46	4	violet group	financial instituion	chiland	June	5	11:00am	4

19:18:48	3	Violet	financial institution	Psiland	April	5	11:00am	6
19:18:52	8	the violet group	financial insititution	epsilonland	April	10	11:00am	4
19:18:58	15	coral	financial institution	tauland	April	10	11:00am	3
19:19:01	13	Violet Group	embassy	Epsilonland	April	5	11:00am	4
19:19:07	9	the violet group	Tauland embassy	Epsilonland	April	10	11:00am	3
19:19:16	7	Violet group	financial institution	Psiland	April	5	11:00am	6
19:19:26	12	violet	embassy	epsilonland	April	5	11:00am	4
19:19:48	12	violet	embassy	tauland	April	5	11:00am	4
19:20:02	15	coral	financial institution	psiland	April	10	11:00am	4
19:20:11	8			omegaland				0
19:20:12	14	Lion	Financial Institution	Psiland	April	10	11:00pm	3
19:20:14	4	violet group	embassy	psiland	April	5	11:00am	5
19:20:16	5	Violet	Financial Institution	Psiland	April	5	11:00am	6
19:20:22	13	Violet Group	Tauland's embassy	Epsilonland	April	5	11:00am	4
19:20:57	6	Violet	financial	Tauland	April	5	11:00am	4
19:21:00	2	Violet			April	5	11:00am	4
19:21:56	4	violet group	financial institution	Psiland	April	5	11:00am	6
19:22:07	12	violet	embassy	epsilonland	April	5	11:00am	4
19:23:17	12	brown	embassy	epsilonland	April	10	11:00am	2
19:23:39	12	brown	embassy	epsilonland	April	10	11:00pm	1
19:24:36	4	Violet group	financial institutions	Chiland	April	5	11:00am	5
19:25:21	12	brown	embassy	tauland	April	10	11:00am	2
19:25:28	11	Lion and Violet		Epsilonland	April	5	11:00am	3
19:25:41	12	brown	embassy	tauland	April	5	11:00am	3
19:26:05	13	Violet Group	Financial Institution	Omegaland	April	5	11:00am	5
19:27:21	8						11:00am	1
19:27:23	4	violet group	financial institution	Chiland	April	5	11:00am	5
19:28:52	3	Violet	Financial Institution	Tauland	April	5	11:00am	5
19:29:00	15	violet	financial institution	epsilonland	April	5	11:00am	5
19:29:10	12	violet	dignitary	epsilonland	April	5	11:00am	4
19:29:25	3	Violet group	financial institution	Omegaland	April	5	11:00am	5
19:29:42	12	violet	dignitary	epsilonland	April	10	11:00am	3
19:30:04	8	violet	financial	omegaland	April	5	11:00am	4
19:30:26	12	brown	dignitary	epsilonland	April	10	11:00am	2
19:30:43	9	The Lion	Tauland Embassy	Epsilonland	April	10	11:00am	2
19:30:47	15	violet	financial institution	omegaland	April	5	11:00am	5
19:31:09	15	violet	dignitary	omegaland	April	5	11:00am	4
19:31:19	3	Violet group	financial institution	Epsilonland	April	5	11:00am	5
19:31:55	12	violet	dignitary	tauland	April	5	11:00am	4
19:32:13	6	Violet	Financial	Psiland	April	5	11:00am	5
19:32:17	2	Violet Group	Financial Institution	Psiland	April	5	11:00am	6
19:32:19	12	violet	dignitary	epsilonland	April	5	11:00am	4
19:32:20	8		dignitary					0
19:32:25	15	violet	dignitary	epsilonland	April	5	11:00am	4
19:32:46	15	violet	dignitary	tauland	April	5	11:00am	4
19:33:23	14	Lion	Financial Institution	Chiland	April	10	11:00am	3
19:33:45	15	brown	dignitary	tauland	April	10	11:00am	2
19:34:12	14	Lion	Financial Institution	Psiland	April	10	11:00am	4
19:36:12	14	Lion	Embassy	Tauland	April	10	11:00am	2
19:36:46	15	violet	dignitary	tauland	April	5	11:00am	4

19:37:56	11	Violet and the Lion	financial institution	tauland	April	5	11:00am	4
19:38:02	15	violet	financial institution	tauland	April	11	11:00am	4
19:38:54	10	Violet Group			April	5	11:00am	4
19:39:50	5	Violet	Financial Institution	Omegaland	April	5	11:00	4
19:40:04	12	brown	embassy	epsilonland	April	10	11:00am	2
19:40:05	4	violet group	financial institution	Psiland	May	5	11:00am	5
19:40:45	14	The Lion Group	Financial Institutions	Chiland	April	10	11:00am	3
19:41:13	14	The Lion Group	Financial Institution	Psiland	April	10	11:00am	4
19:41:42	1	Violet group	the Tauland embassy	Epsilonland	June	10	11:00am	2
19:41:43	8	violet	dignitary	psiland	April	10	11:00am	4
19:41:52	14	The Lion Group	Embassy	Tauland	April	10	11:00am	2
19:42:48	15	violet	financial institutions	omegaland	April	5	11:00am	5
19:43:10	15	violet	financial institution	tauland	April	5	11:00am	5
19:43:51	15	purple	financial institution	tauland	April	10	11:00am	3
19:43:57	12	gold	embassy	epsilonland	April	10	11:00am	2
19:44:30	10		financial institution					1
19:45:50	15	violet	financial institution	tauland	April	5	11:00am	5
19:46:30	15	violet	financial institutions	omegaland	April	5	11:00am	5
19:49:08	15	violet	financial institution	psiland	April	5	11:00am	6
19:49:28	15	violet	dignitary	tauland	April	5	11:00am	4
19:50:07	11	Violet and lion	financial institution	omegaland	April	5	11:00am	4
19:50:37	15	violet	financial insitution	epsilonland	April	5	11:00am	5
19:50:53	10	Violet Group	Financial Institution	Tauland	April	5	11:00am	5
19:50:56	15	violet	dignitary	epsilonland	April	5	11:00am	4
19:54:29	5	Lion with Violet	Financial	Omegaland	April	5	11:00	2
19:58:58	14	The Lion Group	Financial Institution	Chiland	April	25	11:00am	3
19:59:41	14	The Lion Group	Financial Institution	Psiland	April	25	11:00am	4
The Correct Answer		**Violet**	**Financial Institution**	**Psiland**	**April**	**5th**	**11:00am**	

23 June 2006 Data (Hierarchy Organization)

23-Jun-06			Identification Attempts						
			who	**what**	**where**	**when**			**number**
Time	**Player**	**Team**				**Month**	**Day**	**Time**	**correct**
18:46:51	**Game Started**								
18:53:52	3	Who	Coral Group	Financial Institution	Chiland				1
18:54:07	13	What		coalition member embassy					0
18:55:00	3	Who	Coral	Embassy	Chiland				0
18:56:08	15	What	azur	embassy	psiland				1
18:56:21	1	What	Azur	Embassy					0
18:56:48	1	What	azur group	coalition member embassy					0
18:57:23	5	Who	Coral group	embassy	Tauland				0
18:57:44	15	What	azur	embassy	chiland				0
18:59:58	9	When	the Violet group						1
19:00:18	7	What	azur	embassy	epsilonland	daytime			0
19:00:51	6	When				June	5	morning	1
19:01:08	6	When		a visiting dignitary					0
19:02:40	6	When				June	5	11:00am	2

19:02:53	14	Where	Violet group	Embassy	Psiland	May	10	11:00am	3
19:03:40	6	When			Epsilonland				0
19:03:52	11		Violet group	embassy	Psiland	June	5	11:00am	4
19:05:05	5	Who	Coral	Embassy	Tauland	December	19	10:00pm	0
19:05:26	4	Where	Azur	Embassy	Epsilonland	June	15	12:00pm	0
19:07:10	3	Who	Azur	Embassy	Epsilonland				0
19:07:52	9	When	violet group	embassy	Chiland	April	5	11:00am	4
19:07:59	10	Where	Violet group	Financial Institution					2
19:08:15	15	What	azur	embassy	tauland	june			0
19:08:53	15	What	azur	embassy	psiland	june			1
19:10:07	1	What	Coral Group	Embassy	Psiland	June	15	11:00am	2
19:10:28	15	What	azur	embassy	epsilonland	june			0
19:10:28	16	When	Violet	Coalition Member Embassy	Psiland	June	5	11:00am	4
19:10:41	6	When	Purple group	dignitaries	Epsilonland	June	5	11:00am	2
19:10:48	14	Where	Coral	Dignitary	Psiland				1
19:10:49	9	When	Violet group	visiting dignitary	Psiland	April	5	11:00am	5
19:11:14	14	Where	Violet	Embassy	psiland		10		2
19:11:29	3	Who	Coral	Financial Institution	Psiland				2
19:11:53	14	Where	Coral	embassy	Psiland	June	10		1
19:12:12	14	Where	Violet	Dignitary	Psiland	June	10		2
19:12:56	9	When	violet group	embassy	psiland	April	5	11:00am	5
19:14:50	8	Who	violet						1
19:15:34	5	Who	Coral group	Coalition member embassy	Tauland	December	19	12:00am	0
19:16:09	4	Where	Coral	dignitary	epsilonland	June	5	5:00pm	1
19:17:34	10	Where			Tauland				0
19:19:32	6	When	Chartreuse group	dignitaries	epsilonland	June	5	11:00pm	1
19:20:33	4	Where	Purple						0
19:20:38	4	Where	Gold						0
19:20:40	1	What	Chartreuse group	coalition embassy	Epsilonland	June	15	3:00pm	0
19:20:44	4	Where	Brown						0
19:21:04	2	When				June	5	11:00am	2
19:21:15	15	What	azur	embassy	psiland	june			1
19:22:38	8	Who	violet	embassy	chiland				1
19:22:42	4	Where			Chiland				0
19:22:50	4	Where			Psiland				1
19:22:57	4	Where			Omegaland				0
19:23:09	12	Where	Coral	Financial Institution	Psiland	June	10		2
19:23:38	1	What	charteuse group	coalition embassy	epsilonland	June	15	1:00pm	0
19:24:31	15	What	violet	embassy	psiland	june			2
19:25:03	7	What	azur group	embassy	omegaland	june			0
19:27:44	1	What	The violet group	coalition member embassy	epsilonland	June	15	1:00pm	1
19:27:47	7	What	azur	embassy	omegaland	June		1:00pm	0
19:28:02	14	Where	Violet	Dignitary	Psiland	June	10	3:00pm	2
19:29:11	6	When	purple group	dignitaries, embassies	epsilonland	June	5	11:00am	2
19:32:46	3	Who	Coral Group		Epsilonland				0
19:33:04	8	Who	violet	embassy	chiland	June	3	1:00am	1
19:33:37	9	When	the Violet group	visiting dignitary	Psiland	April	5	11:00am	5
19:33:47	1	What				June	1	1:00pm	0
19:34:11	12	Where	Azur group	Tauland Embassy	Epsilonland	June	10		0
19:34:54	15	What	azur	embassy	psiland	june			1

19:35:14	15	What	violet	embassy	psiland	june			2
19:35:45	6	When	the jackal	embassies	epsilonland	June	5	11:00am	2
19:35:46	1	What	the Chartreuse group	coalition embassy	Psiland	June	1	1:00pm	1
19:36:53	3	Who	The Coral Group	Embassy	Epsilonland	June	13	2:00am	0
19:37:11	9	When	violet group	embassy	chiland	June	5	11:00am	3
19:38:04	5	Who	Coral group	coalition member embassy	Epsilonland	January	24	4:00am	0
19:38:49	6	When	The Jackal	Embassies	Tauland	June	5	11:00am	2
19:39:40	3	Who	Violet Group						1
19:41:08	13	What	Coral Group	Coalition Member Embassy	Psiland	October	3	2:00pm	1
19:41:29	4	Where	the Lion	attack dignitaries	Psiland	June	15	11:00am	2
19:42:46	3	Who	Violet Group	embassy	Psiland				1
19:43:28	13	What	Coral	Coalition Member's Embassy	Psiland	December	15	3:00am	1
19:45:54	3	Who	The Violet Group	Embassy	Psiland	June	21	1:00pm	2
Correct Answer			**Violet**	**Financial Institution**	**Psiland**	**April**	**5th**	**11:00am**	

Appendix B - ELICIT game suggestions

A few modest extensions to the ELICIT exercise would provide for improved realism and richer experimental output. With these extensions, ELICIT would more faithfully represent the effect of changes in organization structure on team performance for this C2 task; and ELICIT could be modeled in POW-ER with greater predictive capability and should provide further qualitative and quantitative distinction between Hierarchy and Edge organizations. We offer the following list of suggested changes to the experiment protocol and software for consideration by ELICIT's developers and its users, in the event that an ELICIT users' group is formed.

1. Give players some "factoid source reliability hints" to help them judge the "source reliability" (qualitatively or as a percentage) for each factoid. Players could, for example, be given a characterization of the source for each factoid as: *"reliable", "unknown"* or "*potential source of misinformation"*. This source information could be given to different players than the ones who received the original factoid, so players would have to exchange information to rate the reliability of the source for each factoid.

2. Allow the players to request specific information from the coordinator (in Hierarchy mode) and/or other players (in both modes, but especially in Edge mode) such as: "W*here is the Coral group?"* This would address our concern about introducing alternative forms of exception handling to ELICIT whose availability and effectiveness would differ with different organization structures.

3. Penalize players for wrong answers, perhaps in terms of *reputation points* and give them feedback about wrong answers. For instance, each player could begin with ten points and lose one for every wrong answer, or gain one point for every correct answer. Each player could be given a secondary goal of maximizing their points. The game administrator might be the objective observer who could manage these points and communicate them to players. This would address our concern about providing players with feedback.

4. The game might have some rules for early termination when a single player, a plurality of players or a majority of players achieves the correct answer for the game. This would allow researchers to compare empirical vs. predicted (by the simulation) project completion durations which we cannot do now. This also seems to us to increase realism

in the exercise. If a potential adversary were identified in a real counterespionage or counterterrorism scenario, presumably they might be able to be apprehended for questioning and their person and premises searched, etc. which could begin to confirm or disconfirm the diagnosis.

CRGP Collaboratory for Research on Global Projects

Hypothesis Testing of Edge Organizations: Empirically Calibrating an Organizational Model for Experimentation

Doug MacKinnon, Marc Ramsey,
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http://crgp.stanford.edu

Acknowledgements: OASD-NII/CCRP and Center for Edge Power

ICCRTS Conference — Newport, RI, June 19-21, 2007 — *Organizational Issues* Track (I-092)

Agenda

- Motivation
- Research Questions
- Points of Departure
  - Previous hypothesis testing
  - Cognitive Science: Learning and forgetting rates
- Conceptual Model
  - POW-ER 3.2 extensions
- Calibration
  - AROUSAL Exercise
- Validation
  - ELICIT Exercise
    - Edge vs. Hierarchy
- C2 Application
- Theoretical Contributions
- Next Steps

Motivation

- Edge Organization definition
  - No headquarters to rely upon
  - Requires: shared awareness / self synchronization

- Knowledge flow is especially critical for Edge Organizations
  - High levels of strategic & operational knowledge needed at nodes
  - Enables "agility" in an uncertain environment
  - Understanding knowledge growth & decay in Edge organizations - critical for optimizing performance

Research Questions

- How can we model and simulate Edge vs. Hierarchy organizational forms engaged in similar project-oriented tasks, taking account of the impacts of individual learning and forgetting on performance outcomes for the two structures?
  - How can individual skill acquisition and decay be computationally modeled, calibrated, and validated?
  - How are Edge vs. Hierarchy organizations and projects effected by the sum of individual participants' skill growth and decay?

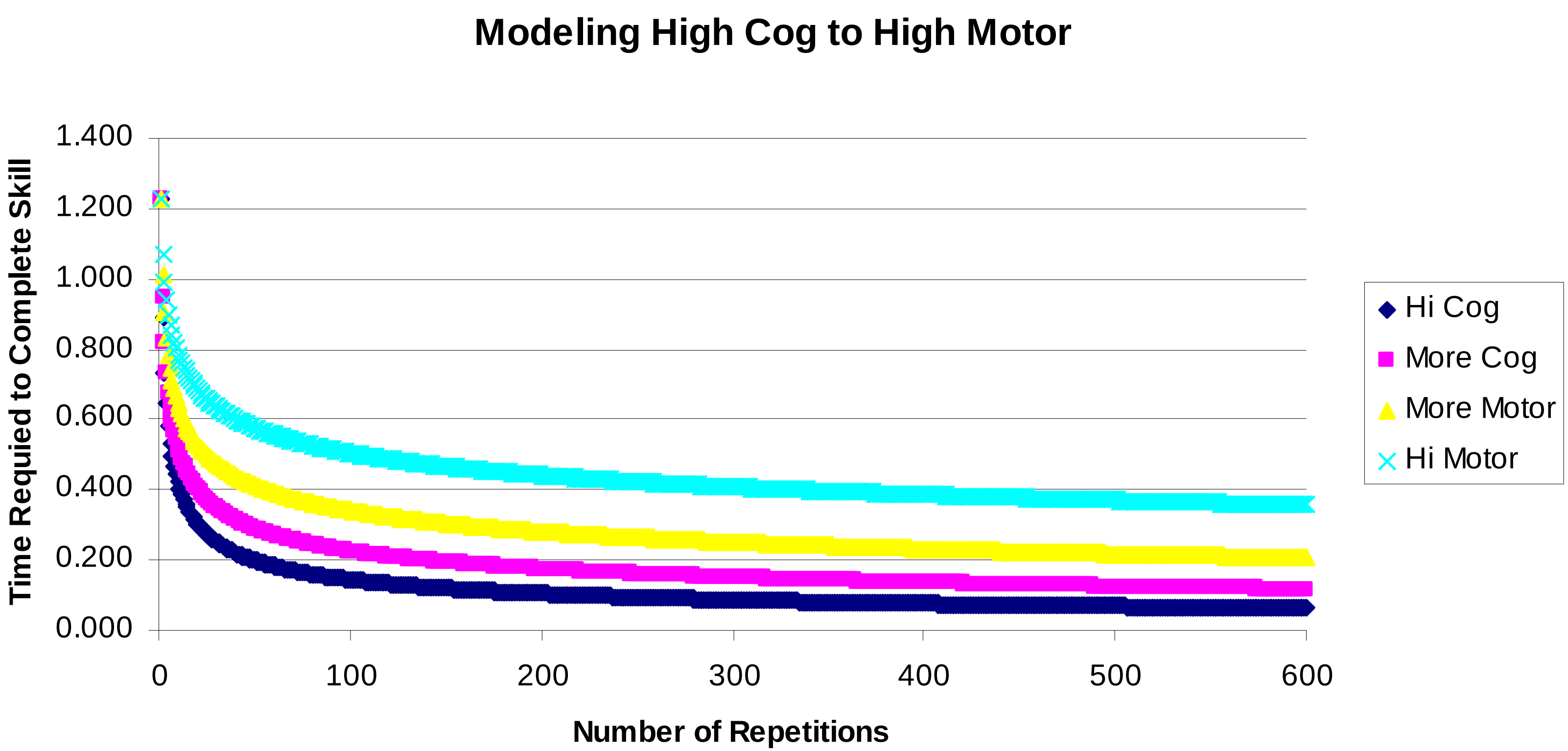
Points of Departure

- Hypothesis Testing of Edge Organizations
    - Nissen, 10th ICCRTS, 2005
    - Orr and Nissen, 11th ICCRTS, 2006
- Cognitive Science
    - Learning and Forgetting rates
        - Anderson, 2005
        - Sikstrom and Jaber, 2004 and 2002
    - Skill Classification
        - Dar-El et al, 1995

Theoretical Point of Departure

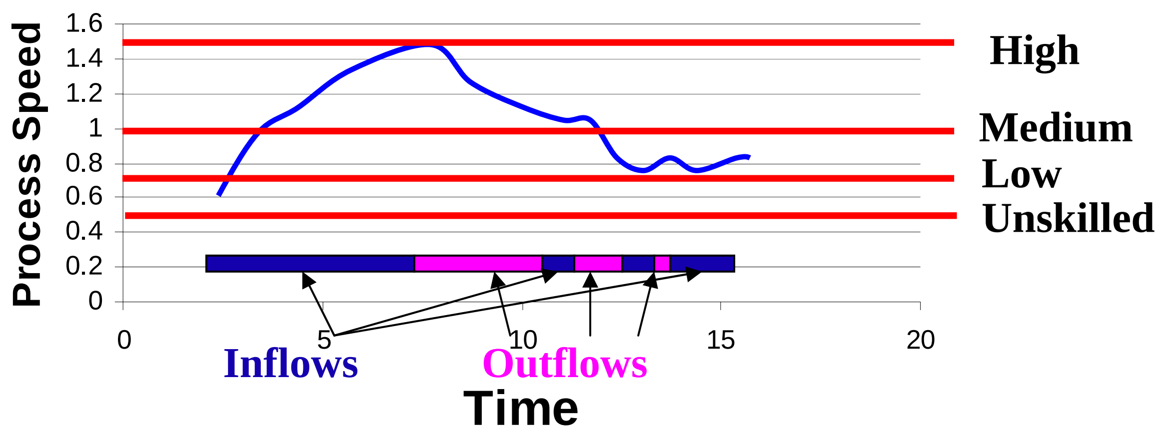
Skill Context (Dar-El et al., 1995)

- Different skill types seem to have different learning curves
  - Ranging from highly cognitive to highly motor skills



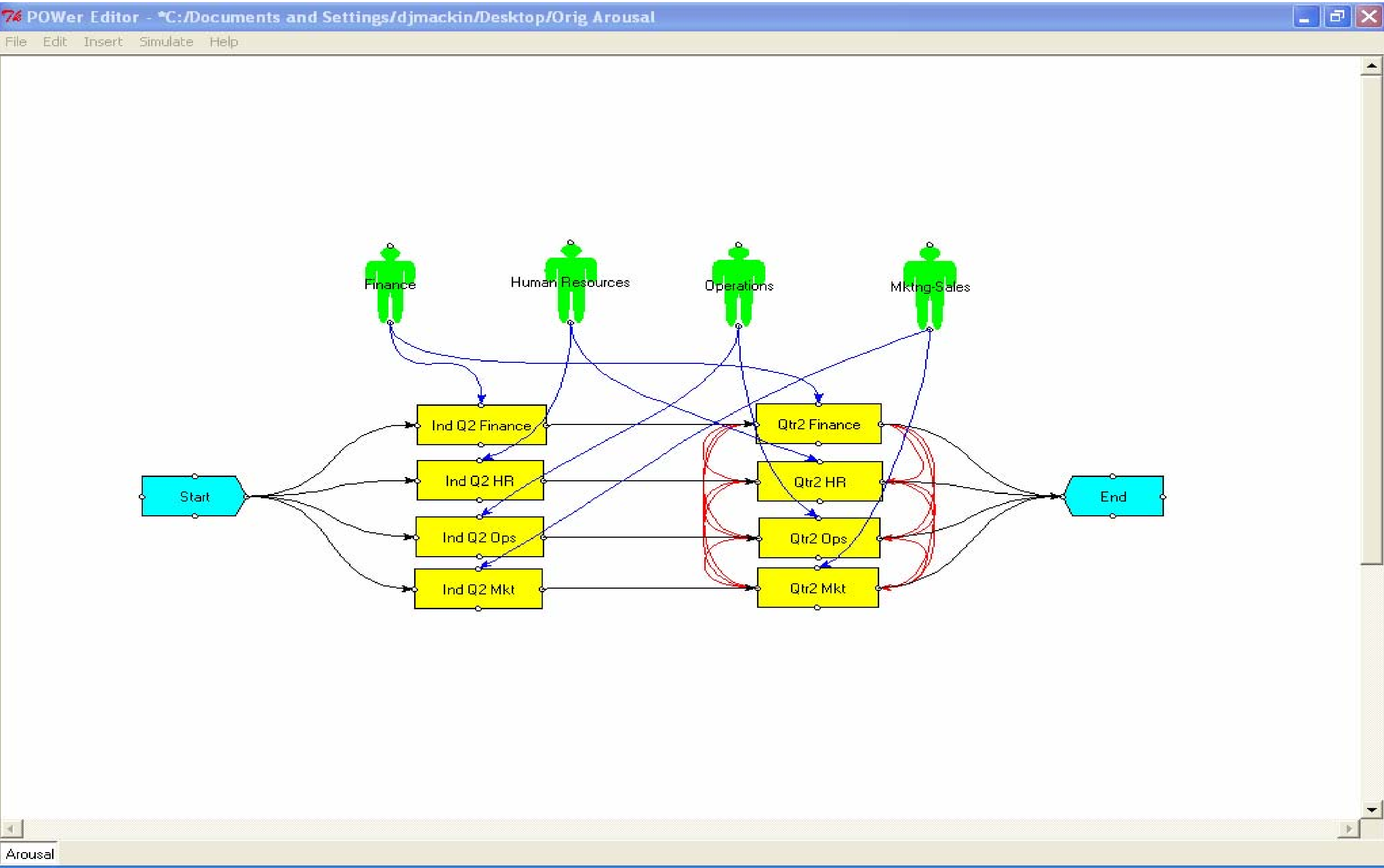
Conceptual Model
Individual Skill Acquisition and Decay

- Extensions to POW-ER computational modeling
- Develop fine-grained agent knowledge metric
  - Provide for dynamic, continuous knowledge over time
- Focus on individual knowledge
  - Inflows through OJT
  - Outflows through decay



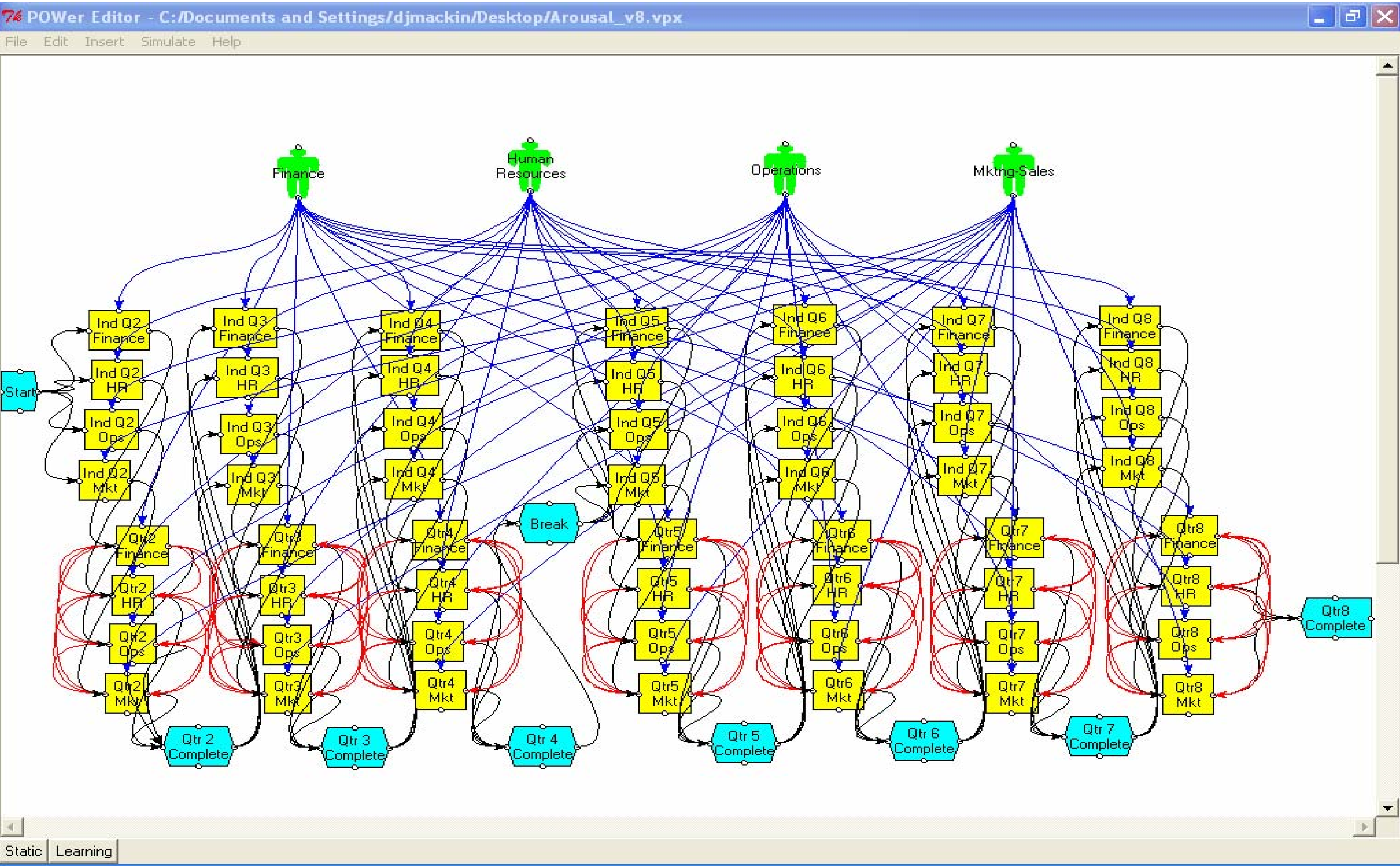
AROUSAL Model

POW-ER 3.2



AROUSAL Model

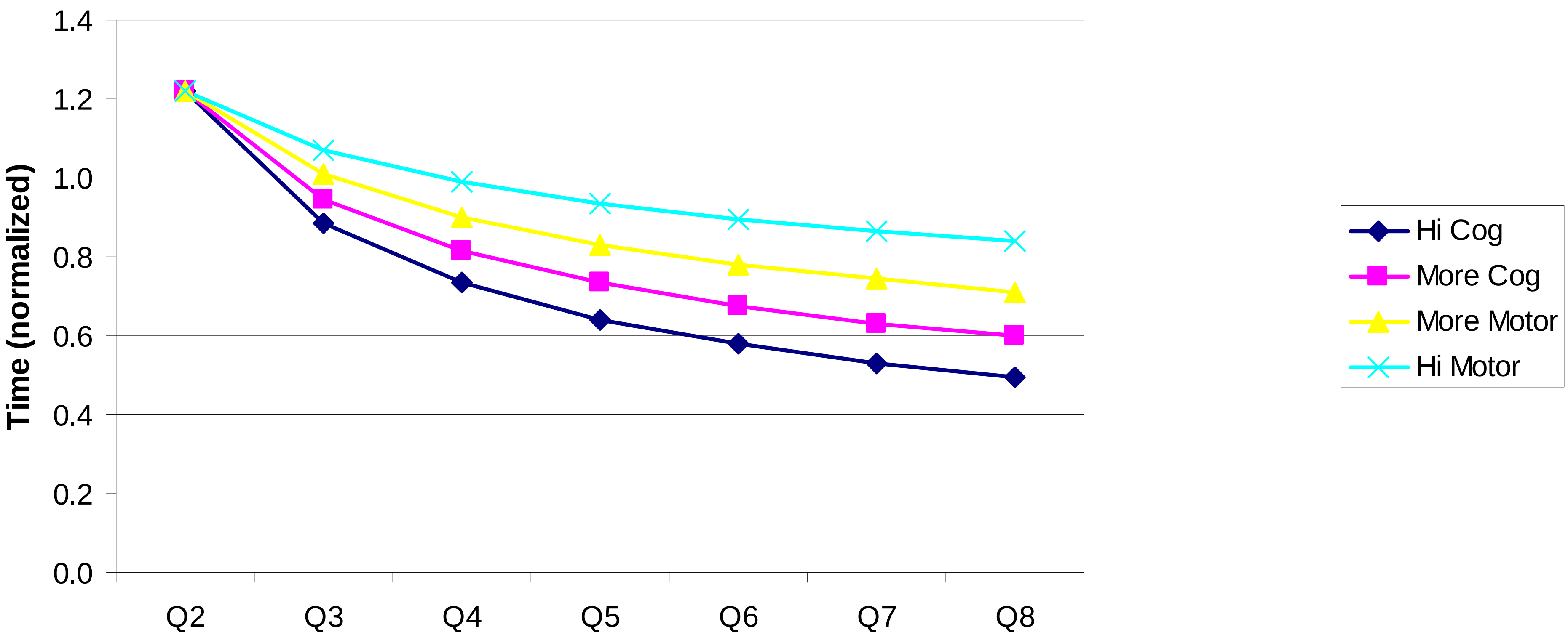
POW-ER 3.2



Empirical Validation of Learning Rates

Arousal Exercise

Dar-El Learning Curves *Plotted Against* Observed Individual & Group Learning Rates



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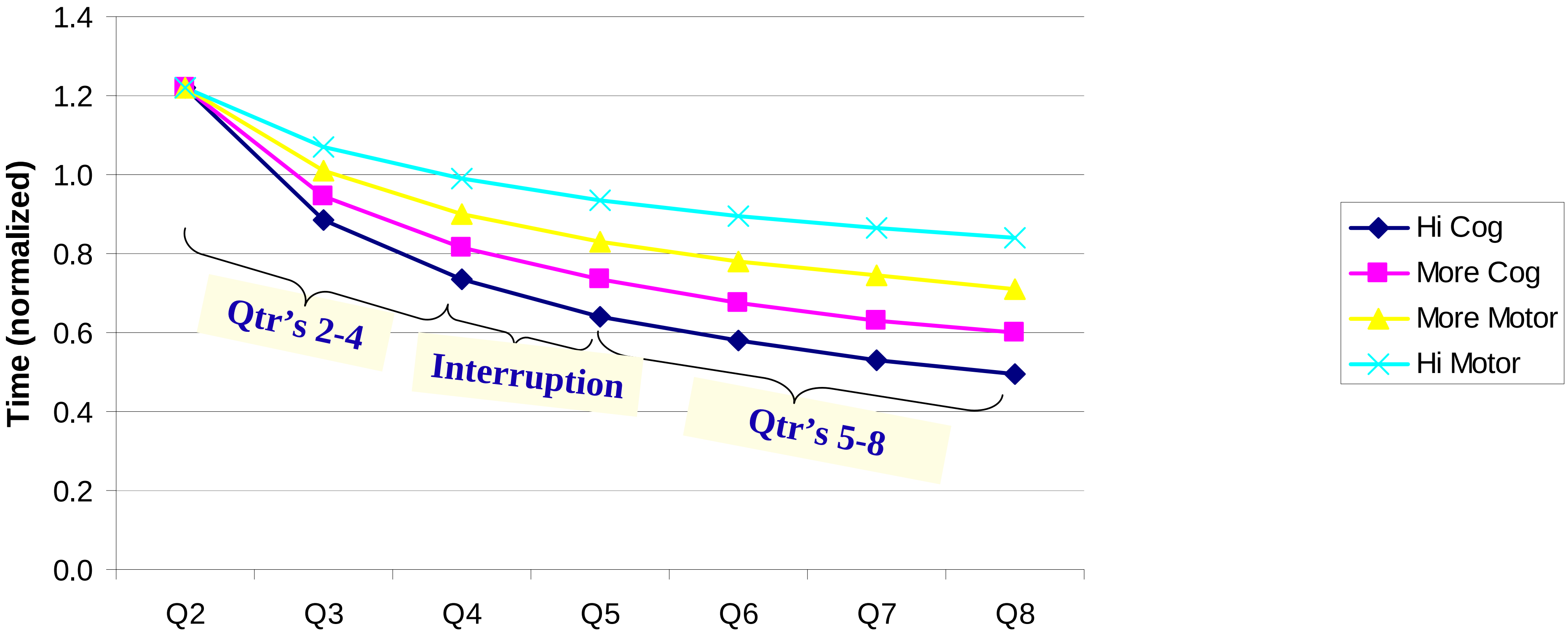

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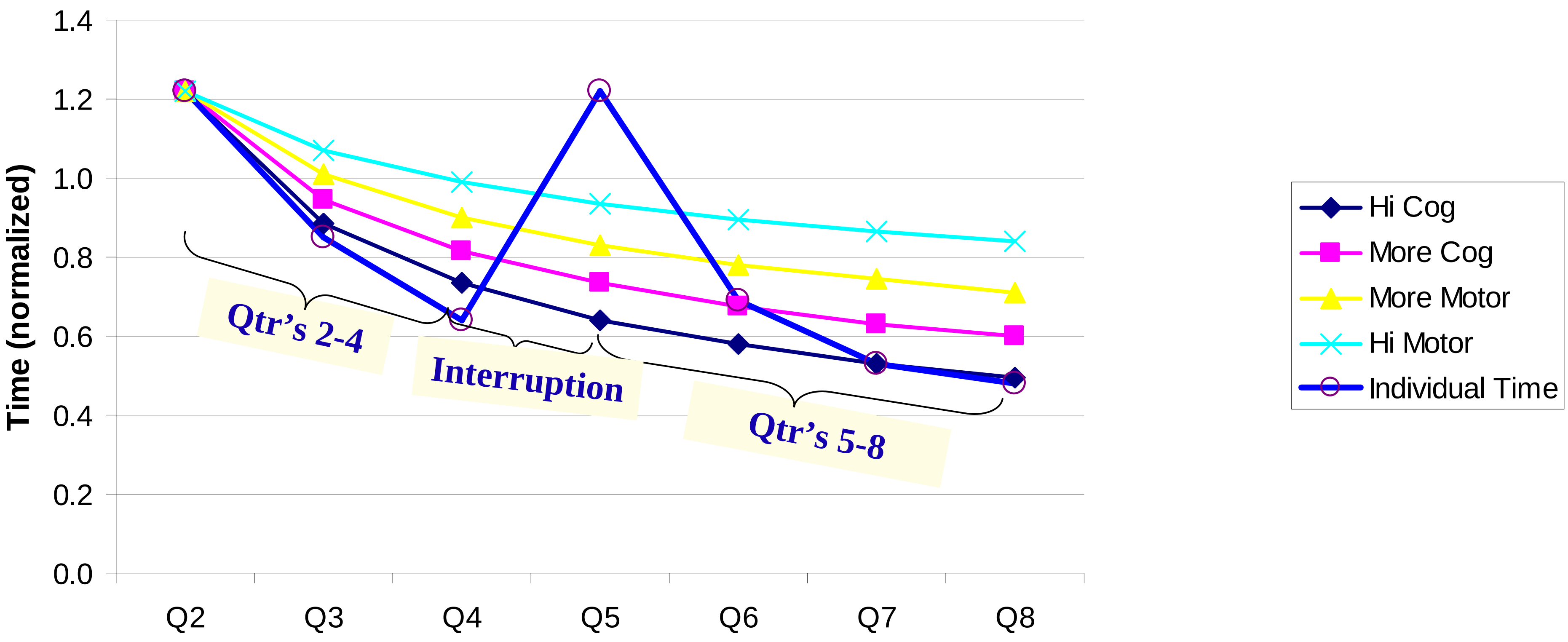

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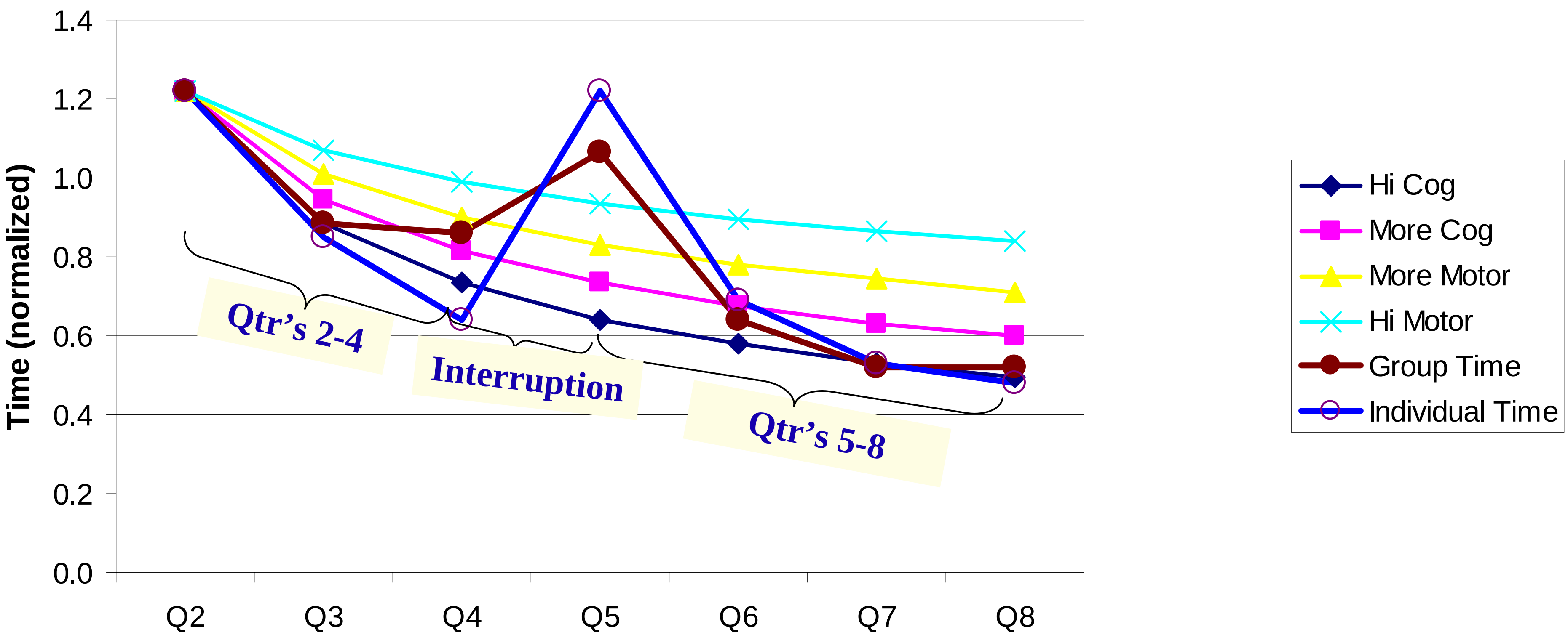

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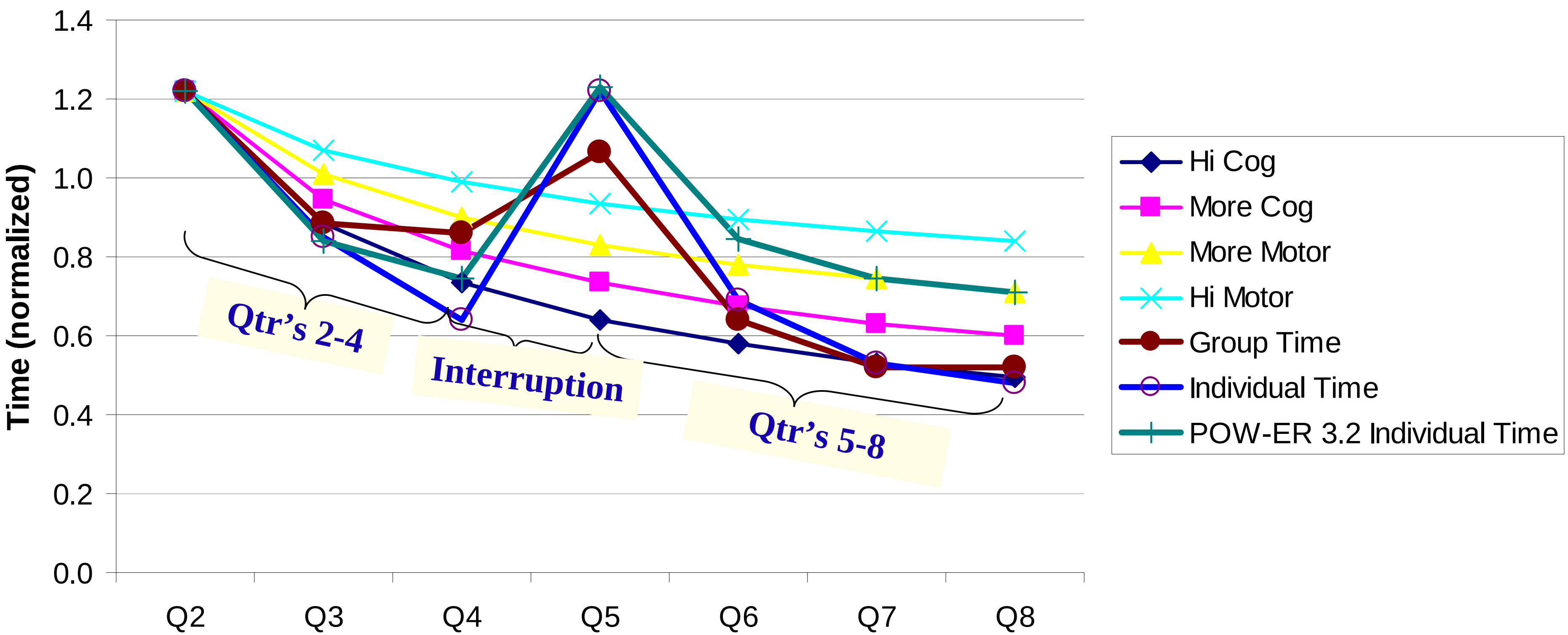

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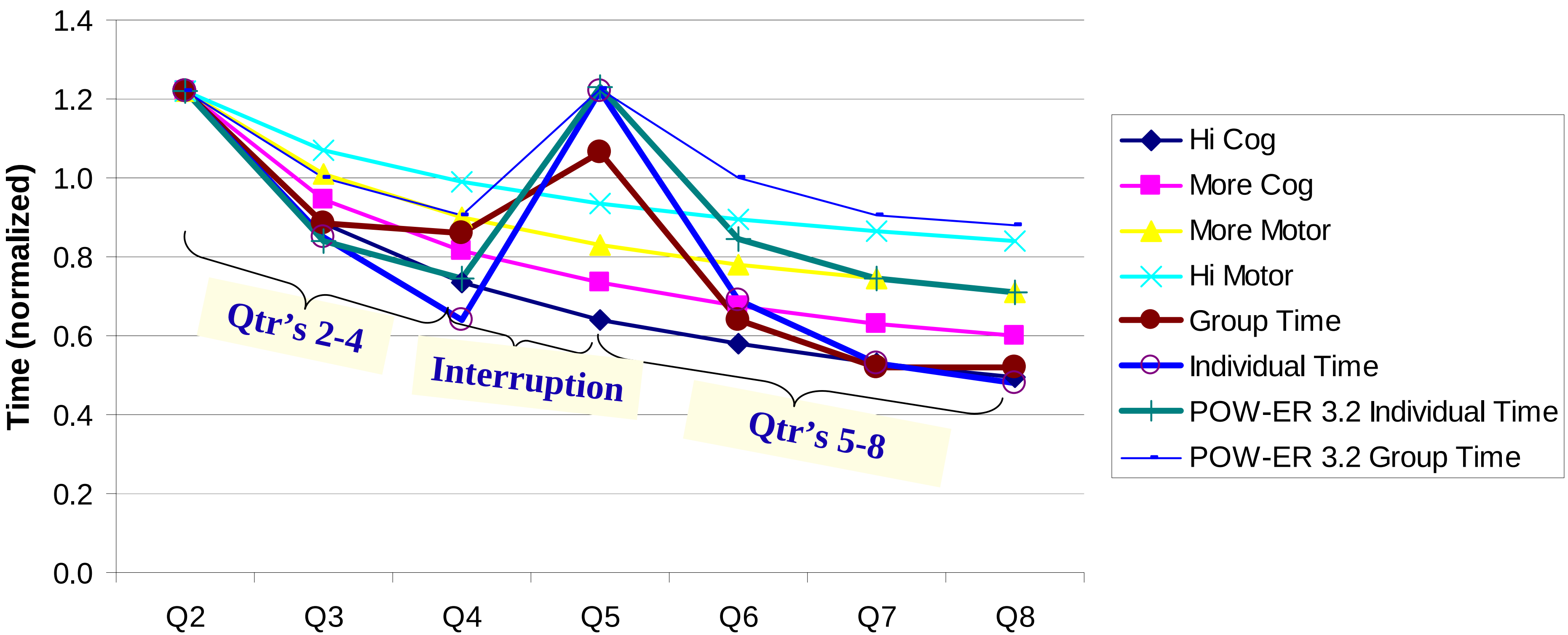
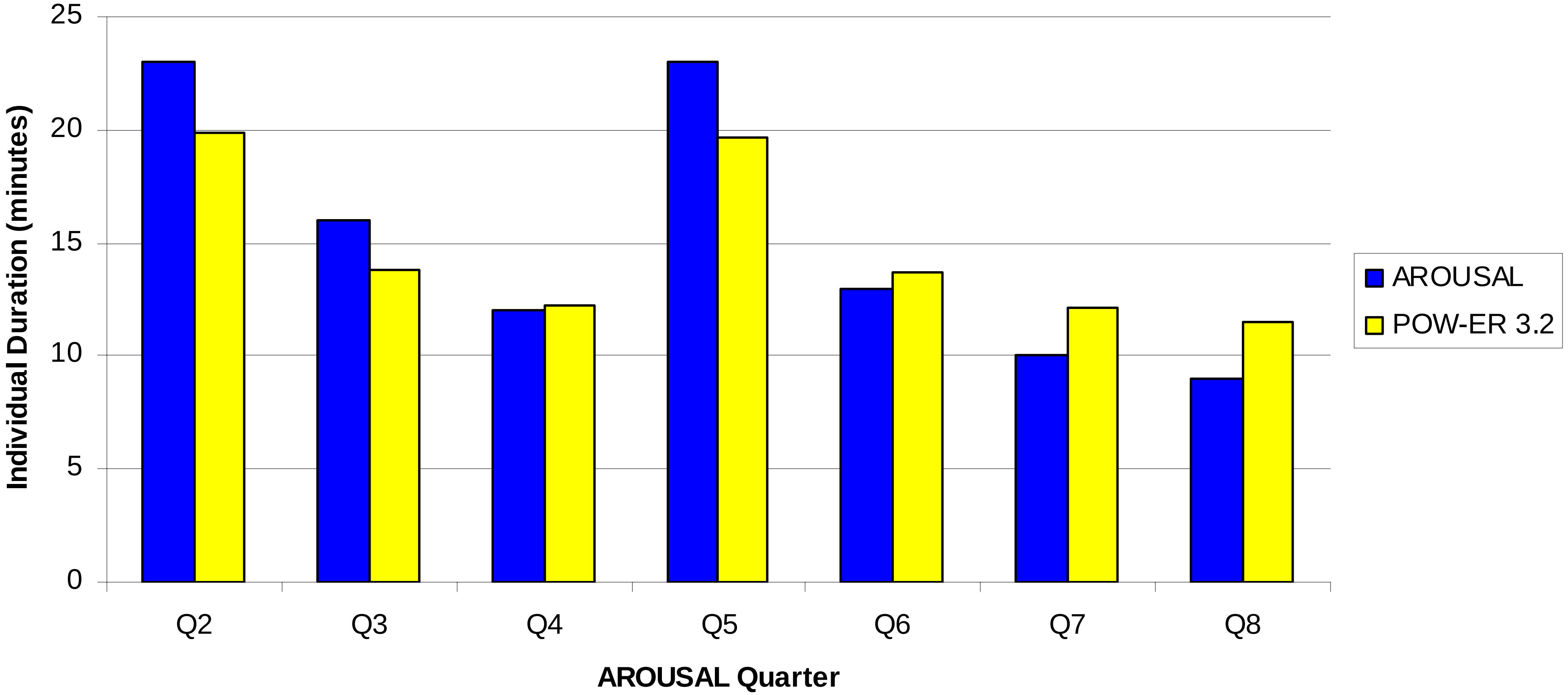


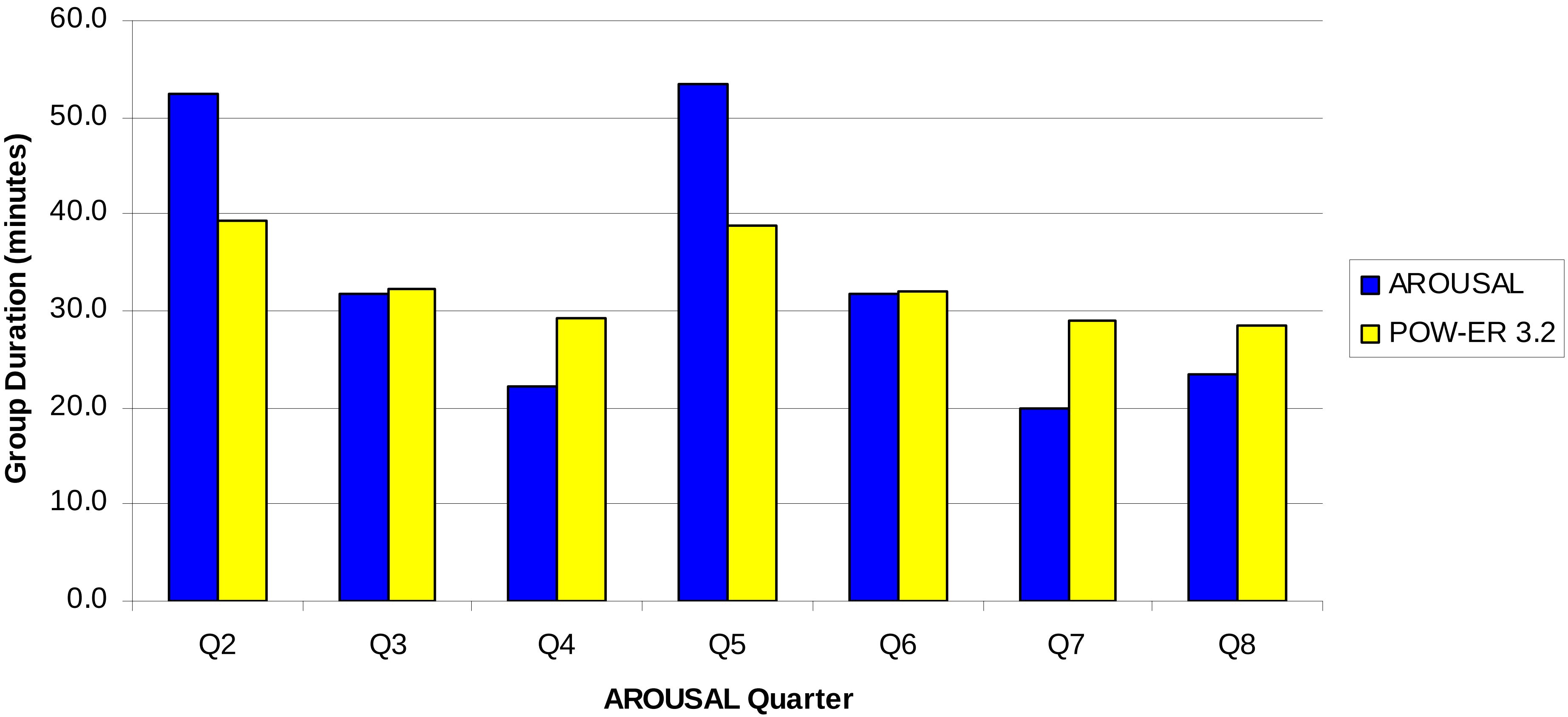
POW-ER Validation

Empirical vs. Predicted **Individual** Performance



POW-ER Validation

Empirical vs. Predicted **Group** Performance



Organizational Level POW-ER Models

Empirical findings from AROUSAL learning and forgetting

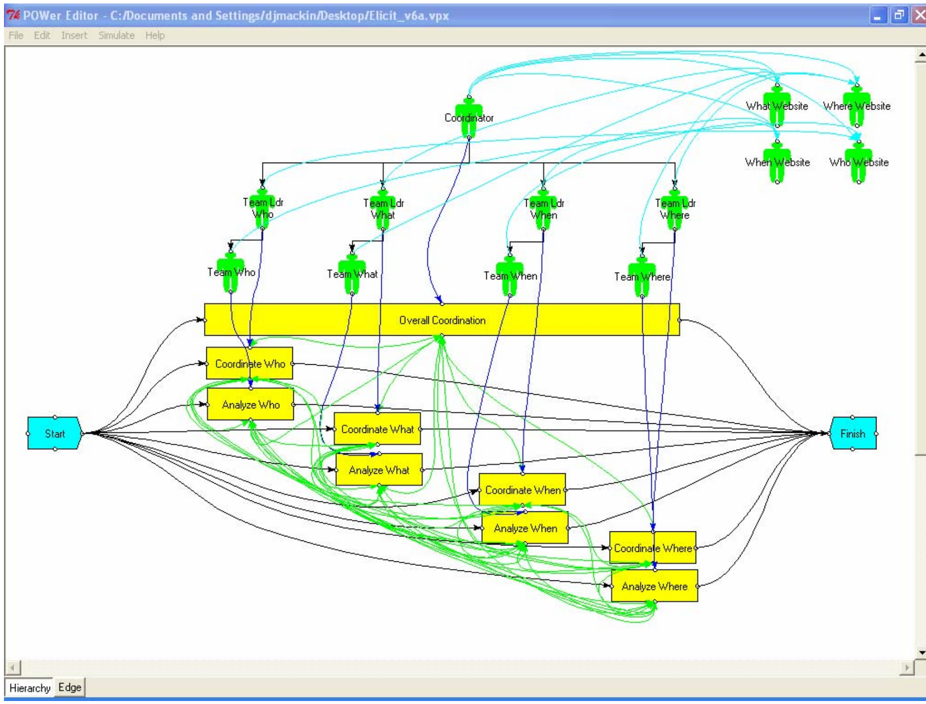
Metric	Individual Data		Group Data	
	Empirical	POW-ER 3.2	Empirical	POW-ER 3.2
Summed individual durations (based on initial period, without subsequent learning)	161 minutes	161 minutes	406 minutes	406 minutes
Duration (with learning)	106 minutes	103 minutes	235 minutes	233 minutes
Percent Savings from Learning	34.2%	36.0%	42.1%	42.6%

ELICIT Exercise

- Anti-terrorist, intelligence (knowledge) sharing game
- 17 players
- Either Edge or Hierarchy organizations
  - All players may share information with each other
  - Hierarchy is limited to viewing own team's website
  - No talking
- Each player required to identify target
  - Who, what, when, where
- Allowed approximately 60 minutes

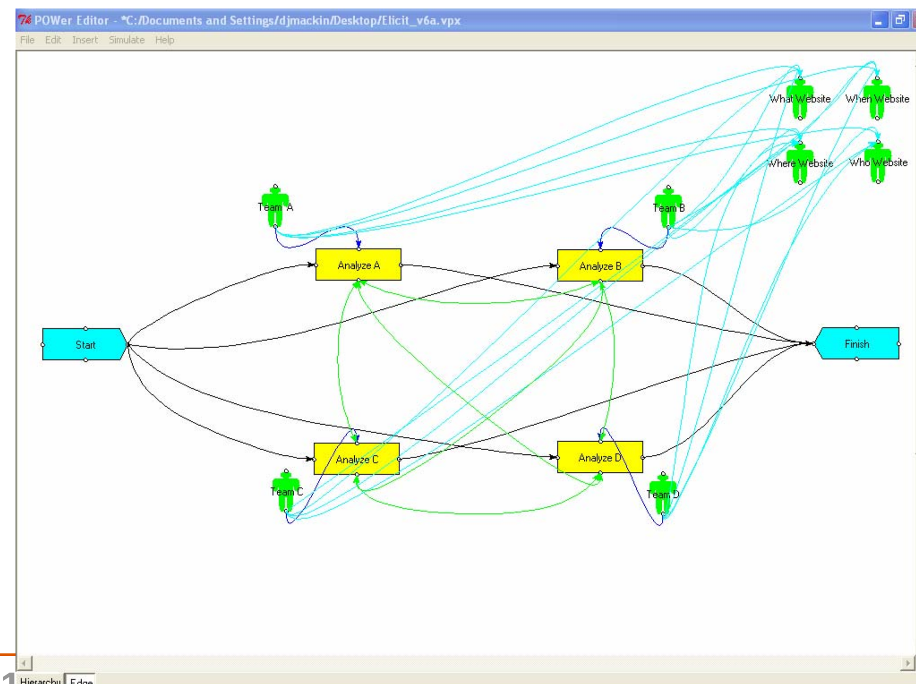
POW-ER Model Validation

ELICIT Exercise

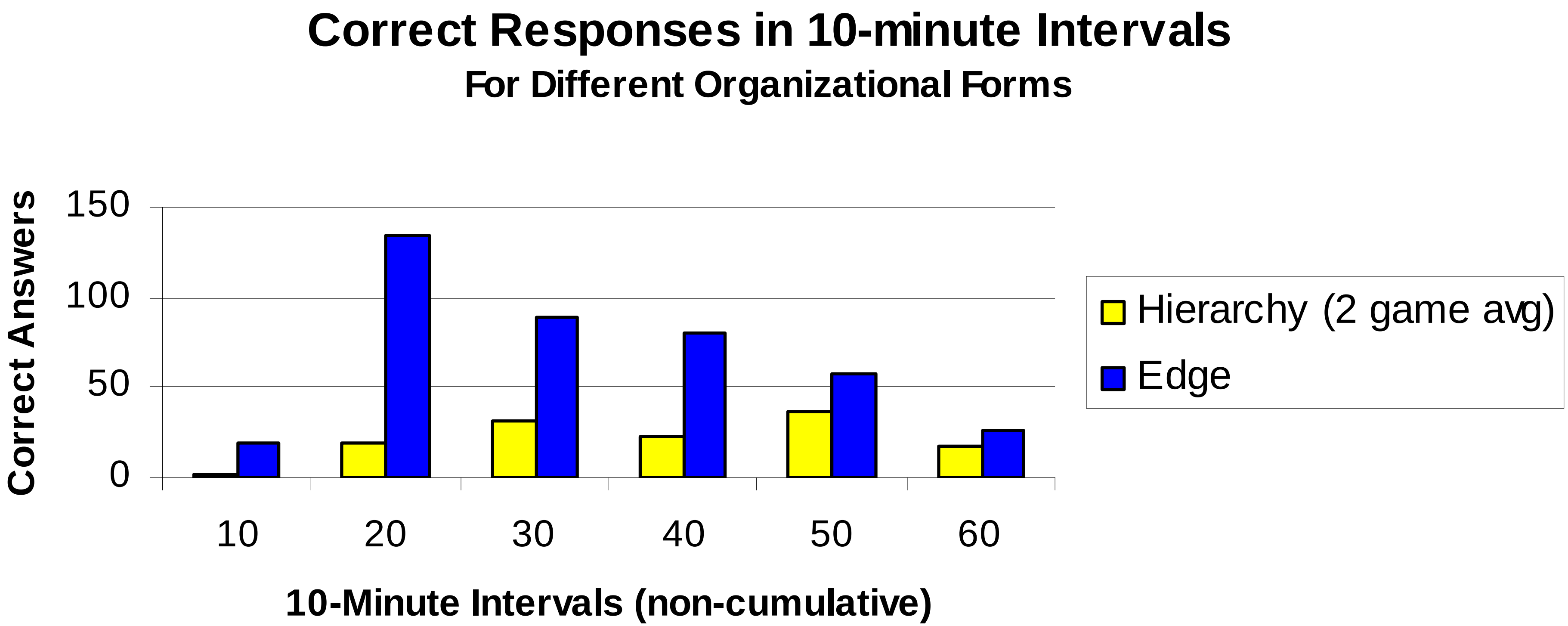


Hierarchy

Edge



ELICIT Exercise



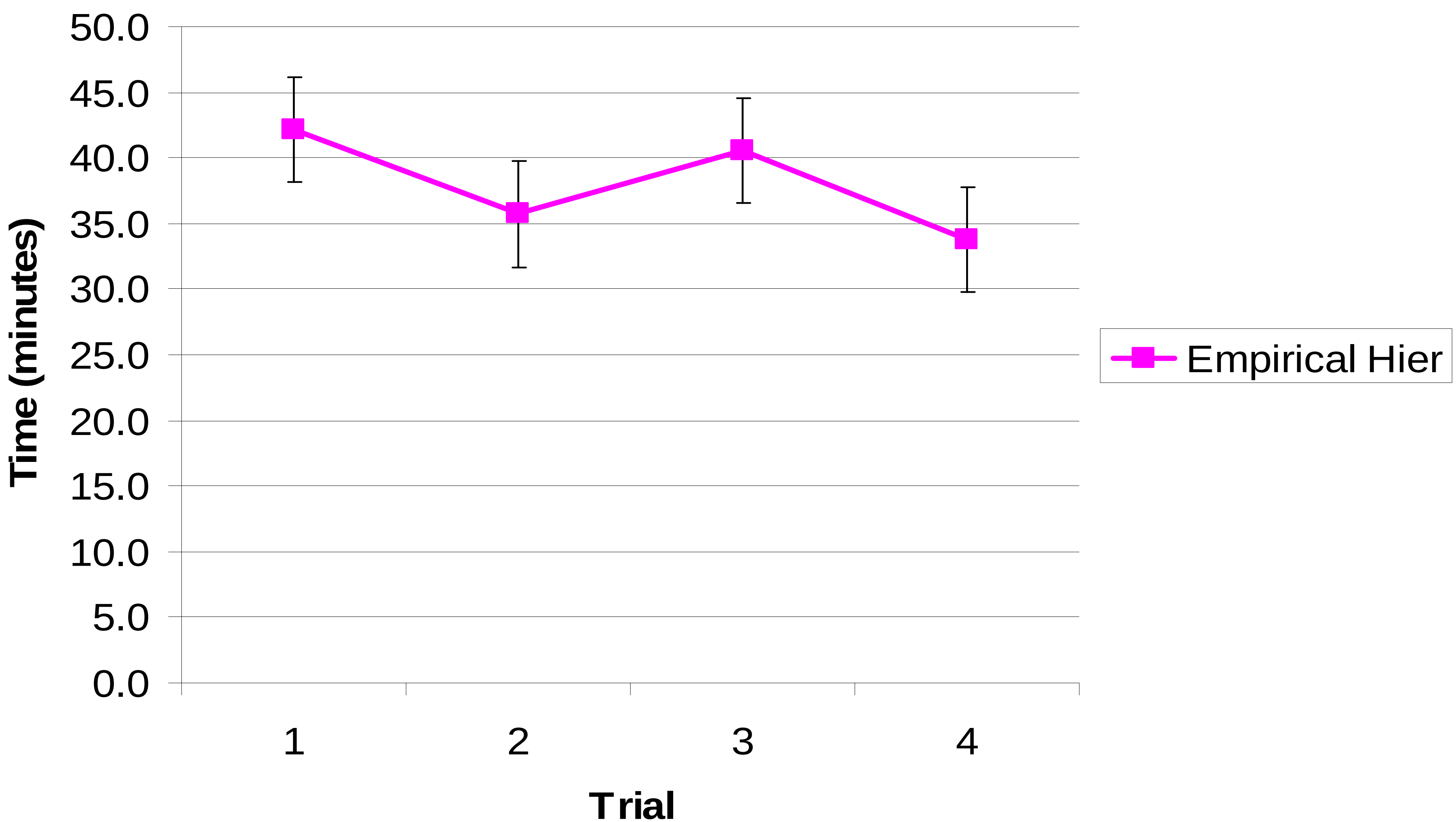
POW-ER Experimental Results

3 Exercise Rounds: 3 day delay after 2nd round

Metric	**Hierarchy (3 Rounds)** Mean (Std. deviation)		**Edge (3 Rounds)** Mean (Std. deviation)	
totals	No learning	With learning and forgetting	No learning	With learning and forgetting
Duration (minutes)*				
Coordination (minutes)*				
Rework (minutes)				
Functional Exception Work (minutes)				
Total Work (minutes)*				
Functional Risk				
Process Quality Risk				
Cost ($K)*				

POW-ER External Validity

Using ELICIT Observations (Leweling & Nissen, 2007)



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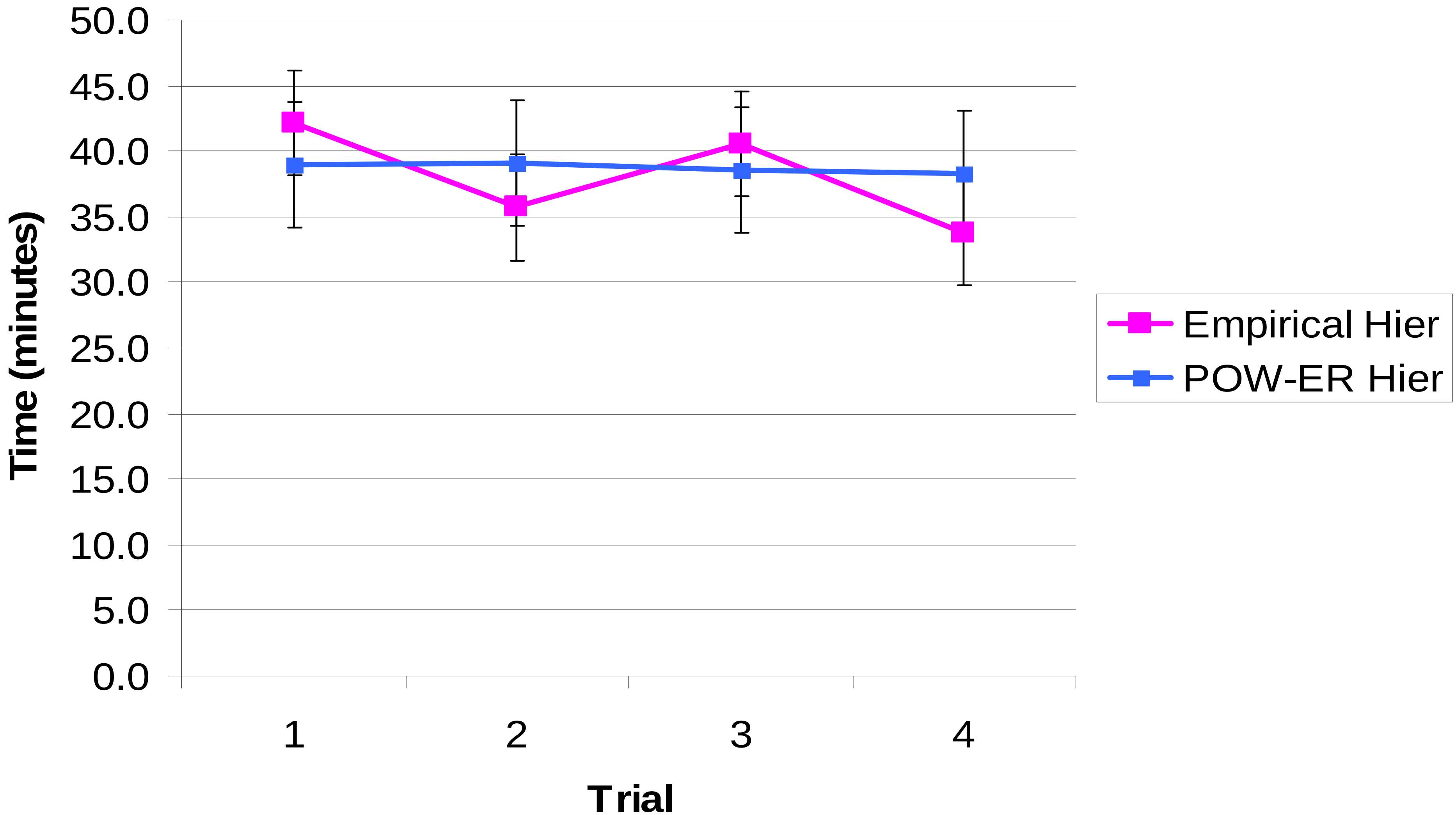

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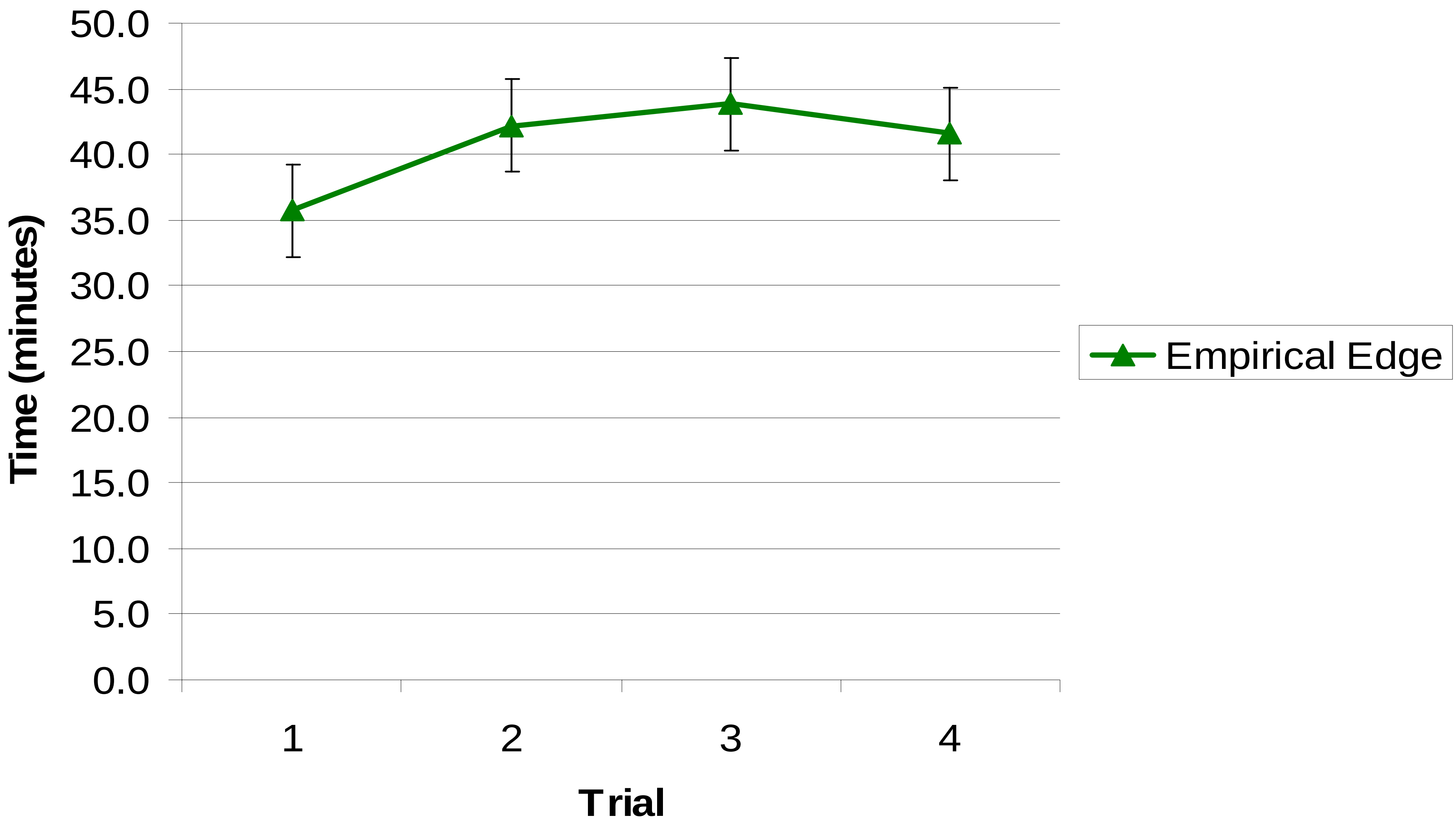

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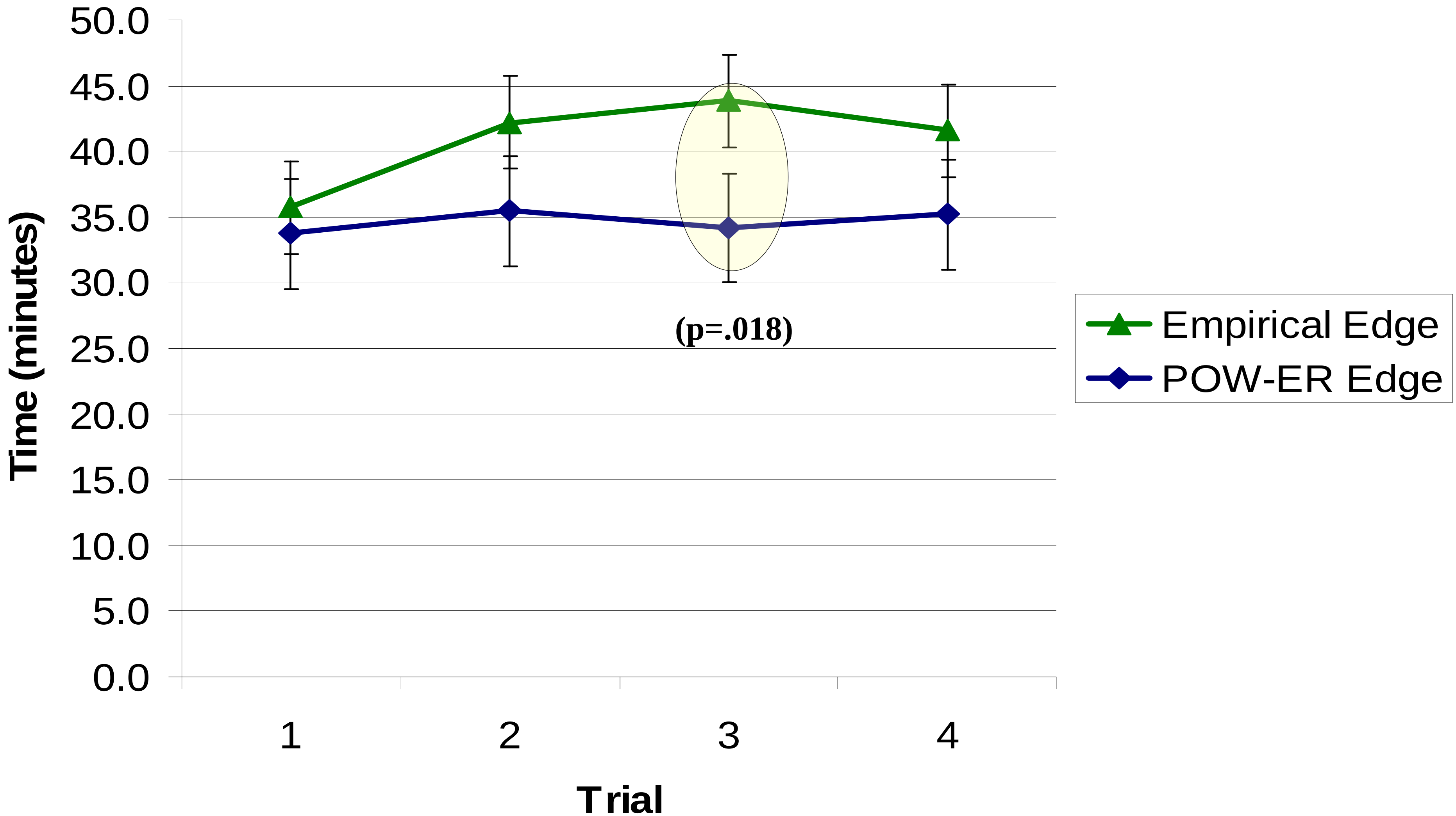

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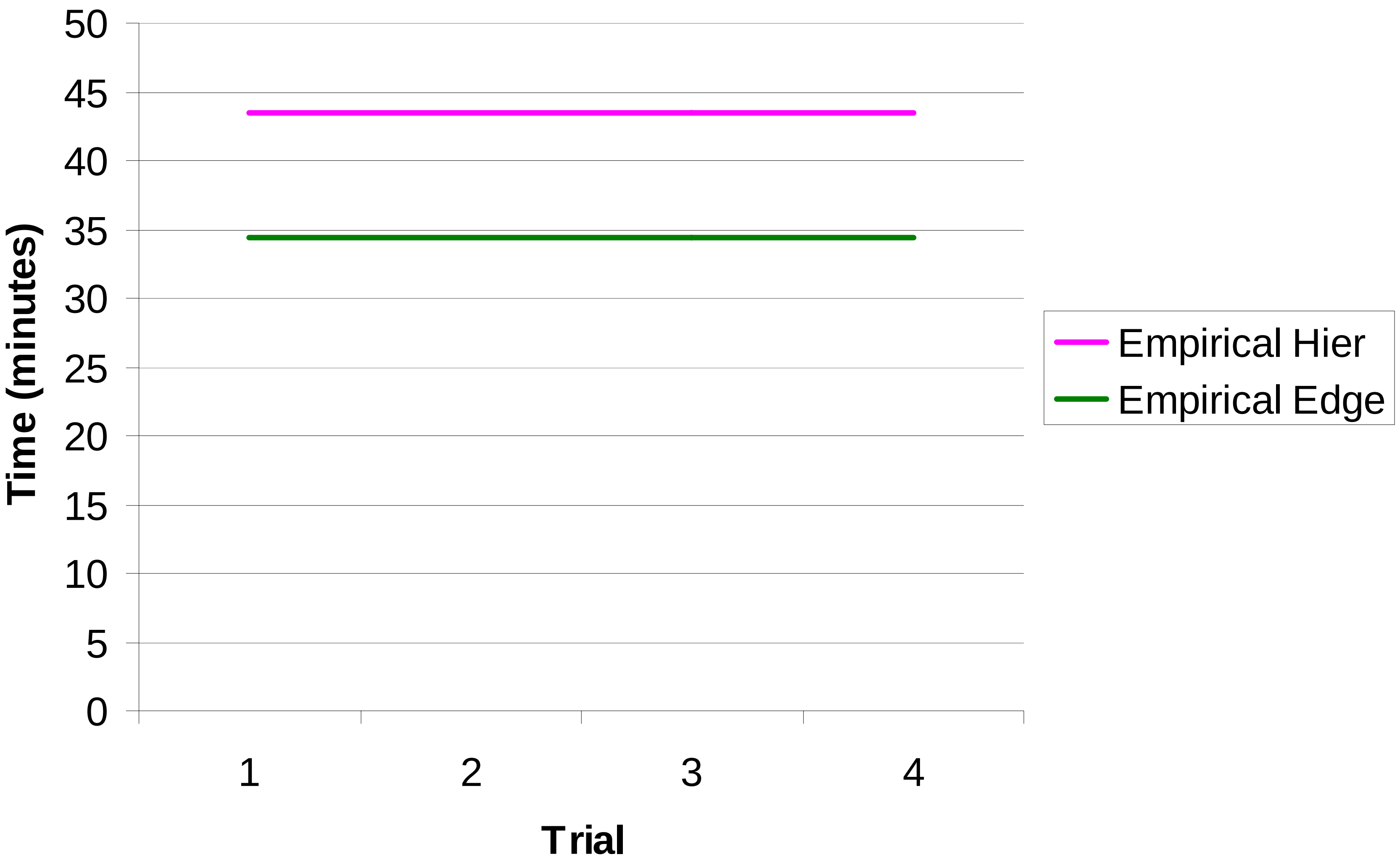

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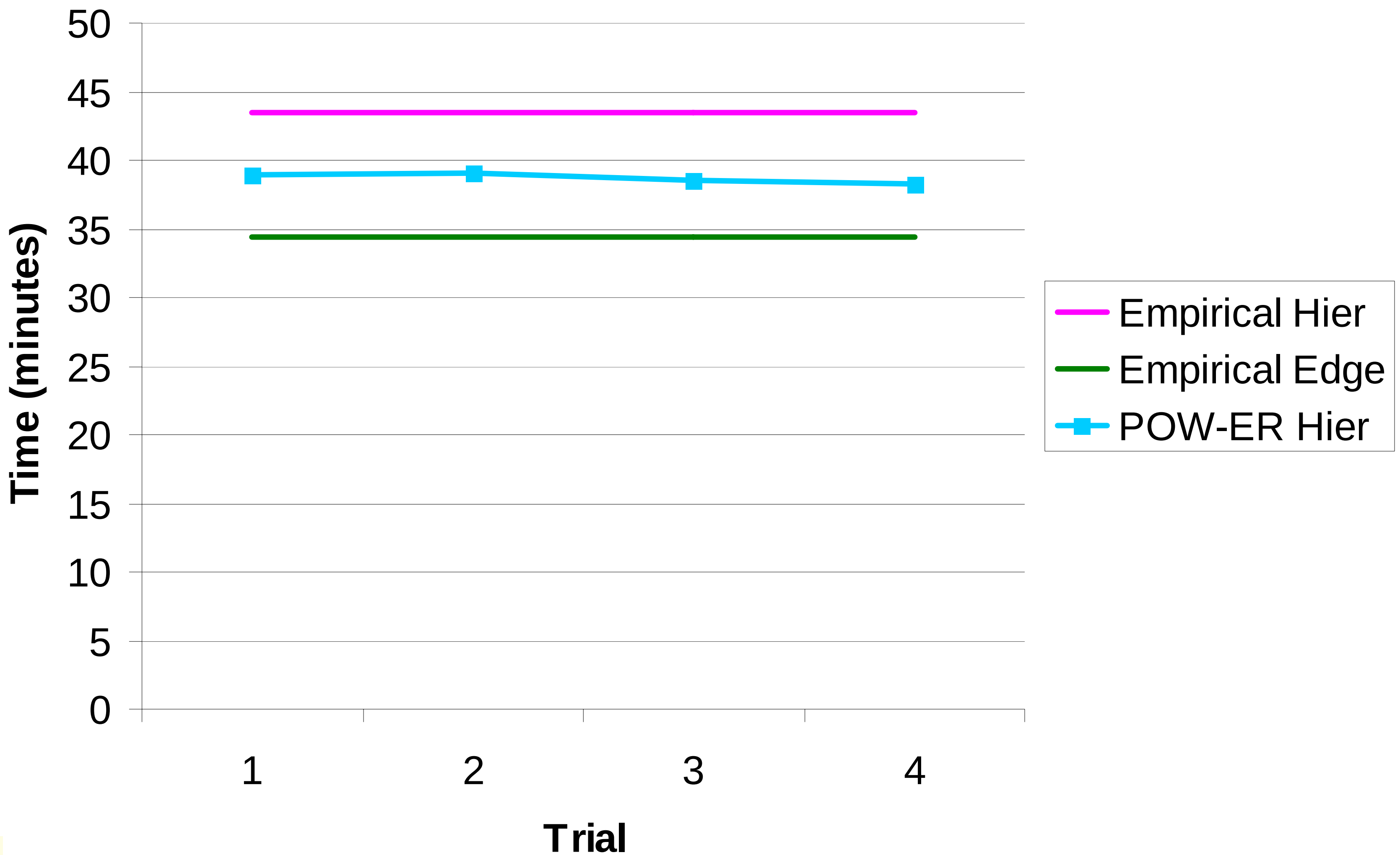

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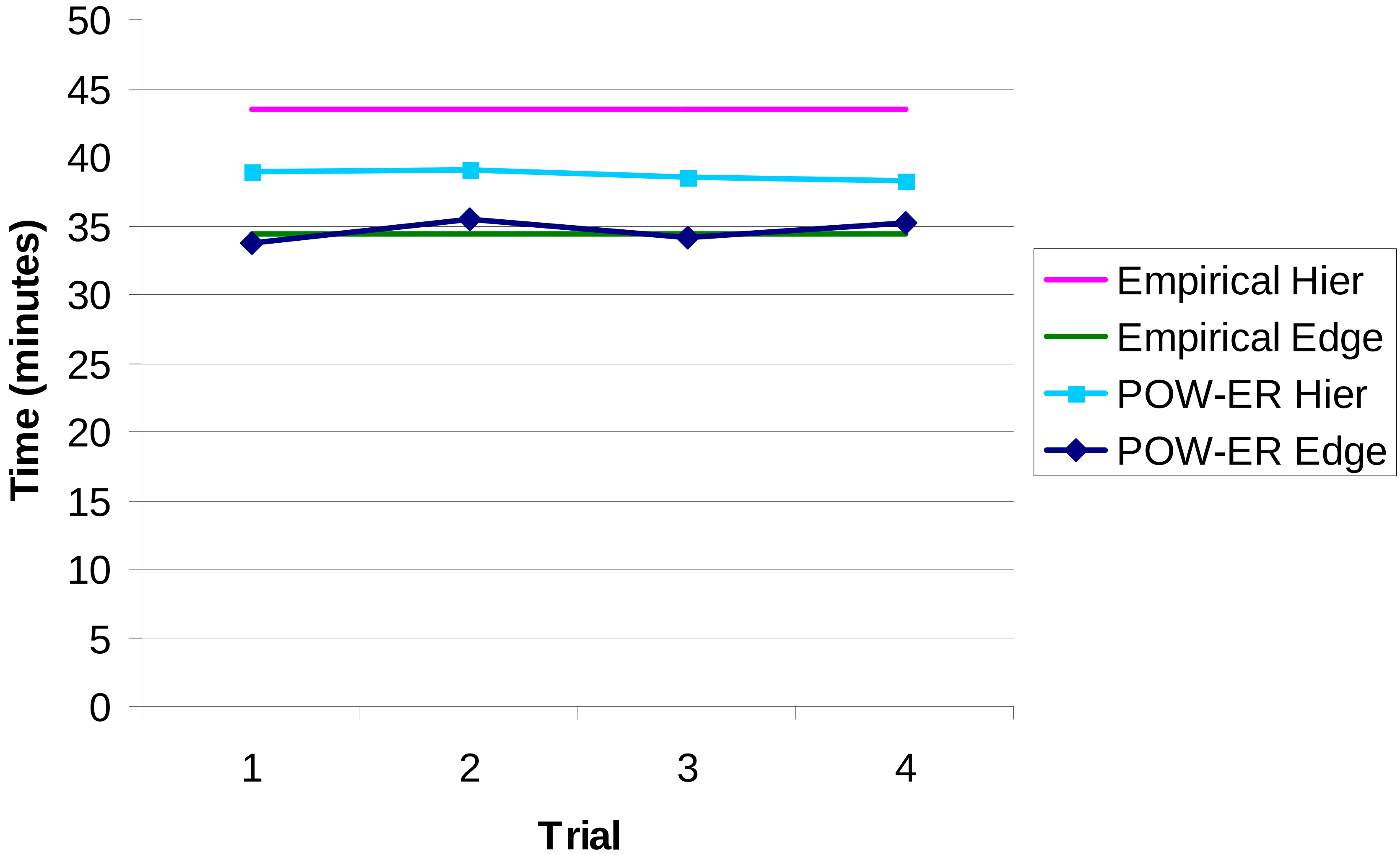

C2 Application

- Example: Crew training (deployment preparation)
  - Consider improvement in command’s performance through adoption of edge-like organizational qualities
- Leverage experimental results to develop and test new command models
  - To predict project lengths for a single project
  - To consider impacts of other agent-based knowledge interventions
    - e.g., training and mentoring

Theoretical Contributions

- Produced quantitative analysis of how micro-behaviors (learning and forgetting) affect organizational performance, extending our understanding of organizational learning
- Calibrated and validated tool to develop and test individual knowledge flow impacts on Edge and other organizational forms

Next Steps

- Develop and validate further via future ELICIT experiments, so that we can
  - Improve our predictions of project lengths for a single project
  - Model the effects of other knowledge interventions
    - Training, mentoring
    - Obsolescence, interference

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